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The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe

Volume 3, Europe

Edited by

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U.S. Department of Commerce

U.S. DEPARTMENT OF COMMERCE

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A Technical Report of the *Fishery Bulletin*

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U.S. Department of Commerce
Seattle, Washington

On the cover

An early etching of oysters of varying ages attached to a block of wood, circa 1880's, courtesy of W. L. Hobart.

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The Mussel Industry of Sweden

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ABSTRACT

Sweden farms blue mussels, *Mytilus edulis*, on a small scale. The Swedish system consists of longlines supported by buoys and uses as mussel collectors 5 cm wide × 8 m long woven strips of polypropylene with edges of terylene silk. The fishery and farming of other mollusks are negligible.

Introduction

Sweden has a small mollusk fishery consisting of the farming of the blue mussel, *Mytilus edulis*, on suspended longlines. The industry began experimentally in 1971, and through the 1970's and 1980's it produced commercial quantities of mussels (Fig. 1, Table 1). The fishery and farming of other mollusks than mussels is negligible, though several attempts have been made to farm flat oysters, *Ostrea edulis*.

Mussel farming was not stimulated by demand for mussels as either fish bait or for the canning industry, but rather because of the discovery that mussels could be farmed in Sweden. The mussel industry has developed slowly in Sweden because the home demand for mussels is small, industry and investors have had little interest in it, and diarrhetic shellfish poisoning (DSP) has become frequent since 1984 and prevents mussel harvests for long periods of the year.

Table 1
The mussel harvest in Sweden, 1983–1991, and export data from 1988 onward in metric tons (wet weight).

Year	Harvest	Exports
1983	1,498	
1984	1,278	
1985	415	
1986	325	
1987	2,566	
1988	858	387
1989	241	81
1990	1,163	1,016
1991	1,643	1,288

Historical Use of Mussels

Blue mussel shells have been found in kitchen middens at Rottjarnslid located about 100 km north of Goteborg. They are dated at about 5,000 B.C. The middens also contained shells of flat oysters, *Ostrea edulis*, and cockles, *Cardium edule*, fish bones, and fish hooks. It is impossible to tell whether the mussels were used as bait or food. Before World War II, mussels were used mostly as bait in the longline fishery. People in fishing areas did not eat mussels, but they were eaten to a small extent by people in cities. About 300 t/year were canned for human consumption.

During World War II, a shortage of fish led to an increase in mussel consumption. People harvested mussels mostly by hand from small boats. In 1945, 973 t of mussels were landed. Between then and 1970, mussel landings stabilized at about 500 t/year. In 1970, Swedish production of canned mussels ceased due to competition from low-priced mussels imported from Denmark. From 1937 to 1984, no interruptions in mussel harvests were noticed due to toxic mussels being eaten.

Development of Mussel Farming

The idea of growing mussels on longlines stemmed from observations in 1966 that mussels set heavily and then grew well from the sea surface down to a depth of 20 m on a mooring for hydrographic instruments. The observations led to the establishment of experimental farms in a sheltered coastal area at the island of Smaget, 10 km south of Stromstad on the Swedish western coast.

The farming method used in Sweden involves longlines supported by buoys (Fig. 2). An important issue when the Swedish farms began was minimization of the amount of labor involved as workers in Sweden at that time (1971) had much higher wages than competing mussel growers in southern Europe. Investment costs also had to be small because Swedish industry and investors had only a mild interest in mussel farming.

The Swedish longline farming unit usually has 10 parallel wires about 200 m long connected at both ends to a 10 m perpendicular rail. The wires are 16 mm in diameter, galvanized, and are surrounded by polypropylene rope. Plastic barrels, 200 l in size, are attached to the wires as buoys. Woven strips of polypropylene with edges of terylene silk are used as mussel collectors. The strips are 5 cm wide and 8 m long.

Under natural conditions in the wild, mussel larvae set mainly on algal filaments such as green algae and diatoms (Bohle, 1971; Bayne, 1976). The terylene silk on the edges of the strip collectors is a good substitute for algal filaments and the mussels spat initially prefer to attach to the edges. The spat later creep over the entire surface of the strips where they settle permanently.

The strips can be deployed quickly in the spring and retrieved quickly at harvest. A rapid installation in the spring enables farmers to install the strips at the right time when mussel larvae are the dominant settling species in the water.

When the strips are deployed during the 2–3 weeks of maximum setting of mussel larvae, about the only species on the strips is mussels. One meter of strip can hold about 10 kg of harvestable mussels. With new mechanized harvesters available, two men can harvest about 30 t of mussels/day.

Farming Strategy

Mussels spawn on the Swedish coast when the water temperature reaches about 10°C in late May. By mid June, the mussel larvae are ready to settle. Mussel farmers follow development of the larvae, and when they are close to settling the strips are deployed. The settling period lasts about three weeks. One worker can deploy from 5,000 to 10,000 m of strips/day, provided the wires in the longline system are anchored at the selected site in advance and the strips are prepared with weights and fixing threads.

When the settlement (Fig. 3) is heavy with 20,000–40,000 spat/m, most of the spat leave the strips by

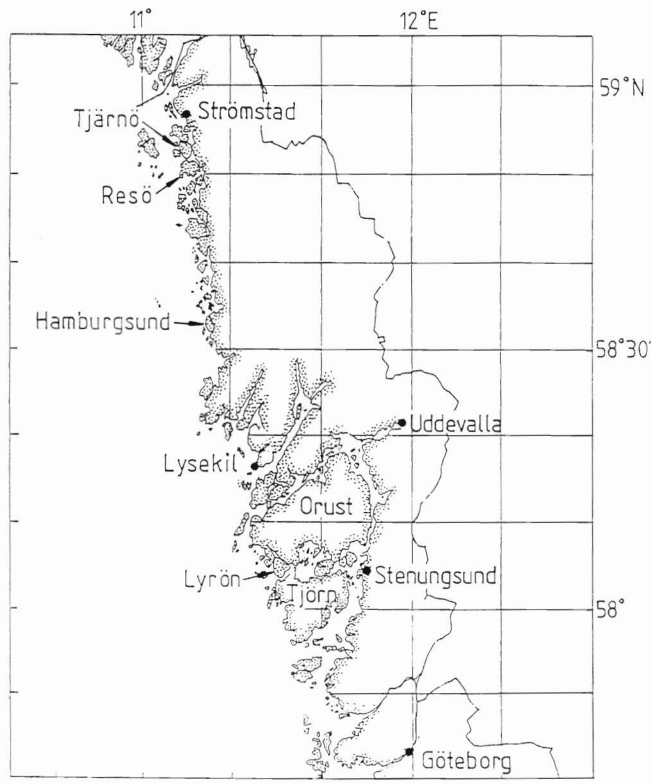

Figure 1
The Swedish farming district.

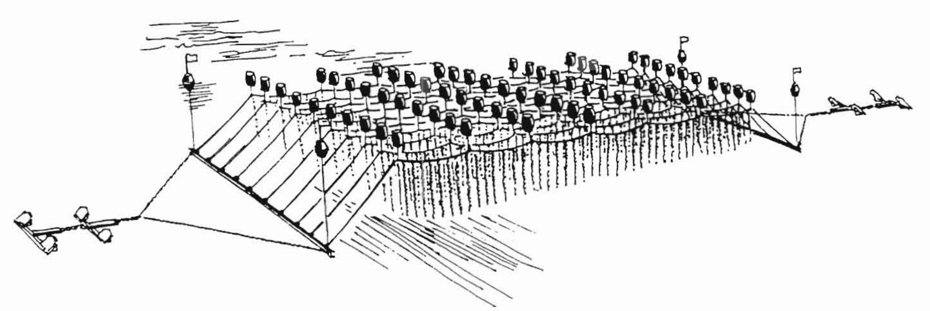

Figure 2
The Swedish longline system with the dimensions 10 × 200 m. The longlines can carry 20,000 m of farming strips with a production capacity of about 200 t in 2 years. The mussel operation consists of 10 wires about 200 m long, supported by buoys 200 l in size, and polypropylene strips 5 cm wide and 8 m long. The mooring is made with two 10 m long rails and four 200 kg anchors.

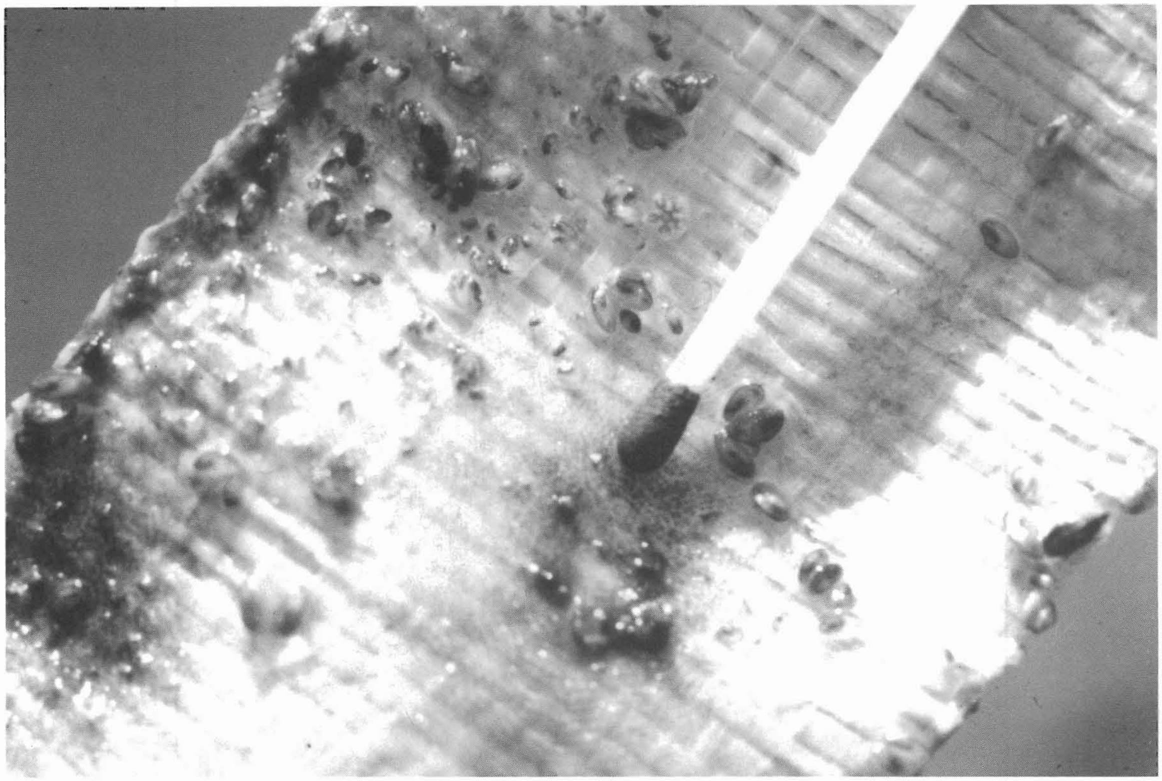

Figure 3
Mussel strip, 5 cm wide, with recently set spat. Match shows relative size of the spat. Photograph by J. Haamer.

themselves when they are small. Most of the small mussels fall to the bottom where they are eaten by starfish, crabs, and fish, or are buried in mud that can be anoxic. In early tests, manual thinning and replanting of small mussels was tried, but was found to be too costly. About 600 adult mussels remain on each strip at the end of the growing season.

The only work carried out between the deployment of collectors and harvest is to add new buoys for increased buoyancy during the mussel growing period. Farmers do not deploy all the buoys to the wires at the beginning so as to reduce wearing of the equipment. The average mussel farm has a production capacity of 150–200 t and occupies 2,000 m^2.

Predators and Fouling

The main mussel predators are starfish, *Asterias rubens*, and eider ducks, *Somateria mollissima*. Starfish larvae can settle on the strips and feed on the mussels, and when numerous, can clean the mussels off the strips. Locations with strong currents and wave action suffer less starfish predation than calm areas, because starfish tend to fall off the strips when agitated. The only method thus far used to get rid of the starfish is to shake the strips vigorously by a diver or by a boat using a crane.

Eider ducks are common on the west coast of Sweden and number about 60,000 in the mussel farming area. Individual eider ducks eat about 2.5 kg/day, mainly mussels. Several methods have been used to prevent the eiders from eating the farmed mussels which they prefer over wild mussels, probably because they have thinner shells. Methods tried, such as hunting, automatic gas guns, submarine sound buoys, and eagle sound, all failed. Several farmers had to give up because of the eiders.

Underwater studies showed the eiders use their wings to swim and stay down. To obstruct their swimming in the farms, wires and strips were placed closer together. The distance between wires did not exceed 1 m and between strips, 0.5 m. In using this method, the eiders can eat only from the outer parts of a farm.

The main fouling organisms on the mussels are the ascidian *Ciona intestinalis* and the polychaete *Pomatoceros triqueter*. The ascidian can become dominant on the strips because it grows faster than mussels. The problem is most severe in areas where currents are weak. *Pomatoceros* larvae settle on the shells of older (>2 years

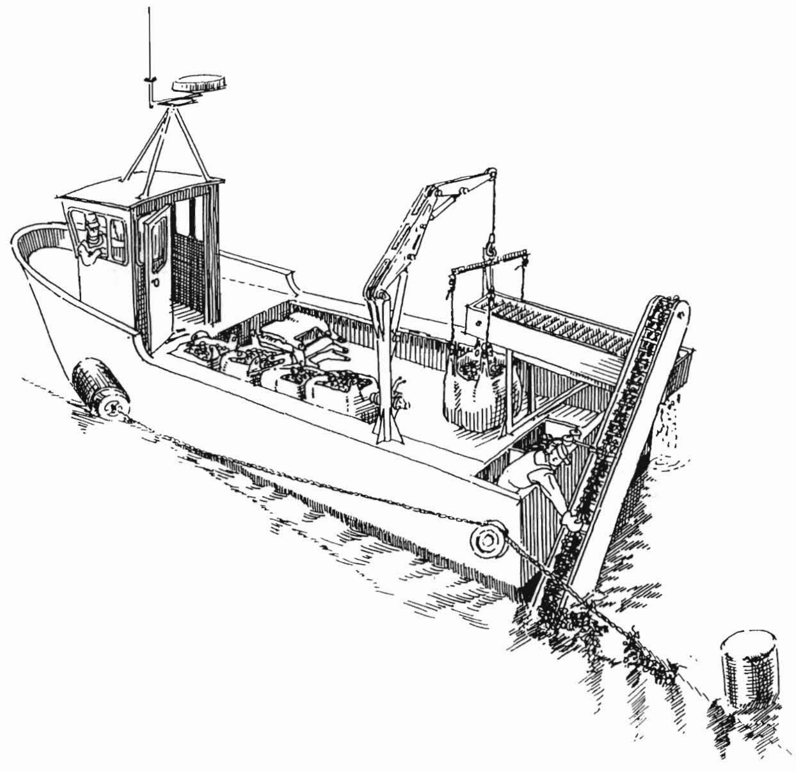

Figure 4
A simplified drawing of the Swedish mussel harvester and a ship-borne cleaning system, designed for longline operations. The harvester is going backward and the mussel strips are loosened by the man standing in the box at the stern of the boat. The mussel clusters are brought up from the water with a submerged conveyor. The farming strips are separated from the mussels half way up the conveyor. On the upper end, the mussels drop into the separator/cleaner. The separator/cleaner takes the mussels to storing sacks as well.

old) mussels and cause problems in the cleaning process if the mussels are packed for the fresh market. The strategy to avoid fouling problems is to choose farming areas where these organisms are less common.

Harvesting

A continuous harvesting method has been developed for the longline system (Fig. 4). Several boats with harvesting devices have been designed. At harvest, the longline wires are lifted onto a power block at the edge of the stern 1 m above the water surface. The wire runs parallel to the boat and the boat runs backward. One man loosens the strips from the wire at the same time as a conveyor catches the strips with mussels just under the water surface and brings them to the cleaning machines. Another conveyor delivers the cleaned mussels into big sacks.

The mussel clusters are brushed off the strips, which are used again. Cleaning equipment for the thin-shelled farm mussels was developed in Sweden in 1983. Brushes are attached to two parallel moving belts. The mussel clusters are brushed from above, and breakage was less than 5%. A harvester with a crew of two can harvest 15–40 t of mussels/day.

Strategies and Life Story of a Mussel Industry, 1979–1984

In 1979, when farming and harvesting equipment had been developed, a new company, Mussellina AB[1], was established to exploit farmed mussels based on this new

[1] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

technique. The company was formed by people from industry and from a university where mussel research and development had been conducted since 1975.

The main objectives of the company were to:

1) Work with mussels year-round,
2) Develop new mussel products based on high quality raw material and to create a market for the products,
3) Farm half of the mussels needed for the production within the company and buy the other half from contracted farmers,
4) Continue with research and development work and follow the development abroad, and
5) Establish shellfish quality control in Sweden to obtain public confidence in the products.

The new mussel products were frozen. This was new for the Swedish market. Three IQF (individually quick frozen) mussel products were produced: boiled mussel meat, breaded mussel meat, and mussels in the shell. A smaller amount of fresh mussels, cleaned and packed in 1 kg net bags was produced. The IQF mussel meat was well received by restaurants, which previously had access only to canned mussels.

The marketing strategy for all the products was initially to concentrate on the catering market. The intention was not to introduce the products on the consumer market from the beginning. Without heavy marketing efforts, there is always the risk that unknown frozen products will remain too long in shop freezers and deteriorate.

The company went bankrupt in 1984 because of 1) costly trials trying to enter the consumer market and 2) the absence of a shellfish toxicity control program in Sweden at the time. When Musselina went bankrupt, the farms were not harvested. Many mussel farms were abandoned and became a nuisance to local governments. Because of this, it is now more difficult to obtain a farming permit, and there must be a bank guarantee for financing the removal of the mussel farm if anything goes wrong.

When the company started after 8 years of experimental farming on the Swedish coast, there had been no known observations of DSP or paralytic shellfish poisoning (PSP) there. The management of the company was well aware of the risks of algal toxins, and for this reason it tried to engage food control authorities in toxic algal control. The local food control laboratory made only mouse tests when the company needed export licenses. In September 1984, DSP was found in the mussels and production stopped. After the company went bankrupt and closed, its processing machinery was sold to Ireland.

In 1983, DSP was observed among people consuming mussels. For that reason, a surveillance system to detect DSP toxins in mussels was begun in 1986. The DSP toxin is the phycotoxin okadaic acid produced by *Dinophysis* spp. (Edebo et al., 1988). Higher DSP toxin concentrations were found in mussels from the outer archipelago than in mussels from more sheltered waters. The seasonal variation in the less sheltered waters often showed a maximum of DSP toxins in the autumn when toxic dinoflagellates were abundant. However, during the spring blooms, normally dominated by diatoms, the toxin disappeared from the mussels.

The mussel harvests in Sweden declined afterward. In 1987, it had a temporary recovery due to harvest of old farms. But the prices for mussels >3 years old were too low to motivate farmers to put out new collectors.

The main consequence of the bankruptcy was that the first wave of enthusiasm for mussel farming faded, and it became difficult to attract new people and capital to mussel farming and processing. The number of farming enterprises declined rapidly from the year 1987 when there were 24 enterprises with a farming area of 294,000 m^2, to 8 enterprises with an area of 112,600 m^2 in 1992. In 1993, the mussel industry in Sweden employed about 10 people. Most mussels now produced in Sweden are exported (Table 1).

The Future

There likely will be a future for the mussel industry in Sweden. The technique for longline farming is functioning on an industrial scale, the control of shellfish toxicity is established with scientific backing, and the finding of farming areas without toxic alga problems all suggest that the Swedish mussel farmers will survive.

Acknowledgements

The drawings were made by Terrence Florell. This chapter is abstracted from two previous papers by Joel Haamer: 1) Strategies for mussel (*Mytilus edulis*) farming in Sweden including larvae catching, growing, predation control, shellfish toxicity control, harvesting and marketing, 23 p., and 2) Presence of the phytotoxin okadaic acid in mussels (*Mytilus edulis*) in relation to nutrient composition in a Swedish coastal water, 23 p. Both appeared in a bulletin edited by the author, entitled "Phycotoxin and oceanographic studies in the development of the Swedish mussel farming industry," Earth Sciences Center, Goteborg University, Publ. A4, 1995.

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The Molluscan Fisheries and Culture of Norway

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ABSTRACT

In coastal Norway, mollusks important for food or bait include the northern horse mussel, *Modiolus modiolus*; blue mussel, *Mytilus edulis*; Iceland scallop, *Chlamys islandica*; great scallop, *Pecten maximus*; ocean quahog, *Arctica islandica*; and to a lesser extent, *Cardium* sp., and the softshell clam, *Mya arenaria*. The Pacific oyster, *Crassostrea gigas*, and Manila clam, *Ruditapes philippinarum*, were introduced in recent years. The iceland scallop also is harvested offshore. The first gear documented for harvesting mollusks may have been an iron rake in 1773. Fishermen later used various types of grabs and dredges. In early times, mussels were generally used as food, but they were, in more recent times, commonly used as bait for fish. The flat oyster was used for food in southern Norway until the beds became depleted in the mid-1800's. Oyster seed after that was grown in pools, but production always was small. In the mid-1980's, the fishery for Iceland scallops in northern areas increased rapidly and peaked in 1987 when 45,000 t (round weight) were landed. Landings fell sharply and were only 2,500 t in 1992. Since the early 1980's, spat of several species have been reared in hatcheries and nurseries, but the cultivation industry is small. The potential for increased mollusk cultivation is good. Mollusks are not commonly eaten in Norway.

Introduction

Along the coasts of Norway, inshore mollusks important in fishery and culture, for food or bait, include the northern horse mussel, *Modiolus modiolus*; blue mussel, *Mytilus edulis*; Iceland scallop, *Chlamys islandica*; great scallop, *Pecten maximus*; flat oyster, *Ostrea edulis*; ocean quahog, *Arctica islandica*; and to a lesser extent cockle, *Cardium* sp., and softshell clam, *Mya arenaria*. Species introduced in recent years are Pacific oyster, *Crassostrea gigas*, and manila clam, *Ruditapes philippinarum*. The Iceland scallop is also harvested in offshore waters.

Shell piles or middens, common at ancient living sites in Norway, date from 6000 B.C. (Simonsen, 1988) and show that mollusks were widely utilized and a common part of daily meals from the Stone Age to the Middle Ages. The most frequent species found in them were the ocean quahog, blue mussel, cockle, softshell clam, common limpet, *Patella vulgata*; and periwinkle, *Littorina* sp. Flat oyster shell was mainly limited to southern Norway. Scallop shells found in childrens' graves from the Iron Age in northern Norway suggest they were used as children's toys then, just as they are today (Bratrein, 1988; Simonsen, 1988). This may explain why scallop shells are seldom found in household wastes from that time, although low accessibility due to their depth distribution is a more likely explanation. In the Stone Age, some shells were used as jewelry; ornaments

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made from scallop shells have been found in grave sites dating from as early as 1500 B.C.

Probably the first mollusk harvesting gear documented was an iron rake in 1773 (Bratrein, 1988); later, fishermen used various types of grabs (Fig. 1). In 1857, a sledge was developed for catching mussels (Bratrein, 1988), a type of gear that eventually developed into the modern dredges like those used in the offshore fishery for Iceland scallop (Fig. 1).

In early times, mollusks were generally used as food. In recent times, however, they have been commonly used as bait in the coastal longline fishery. Using mollusks as bait was first alluded to around 1770, while the first record of commercial exploitation of mollusks was in 1869 (Bratrein, 1988). The dominant bait species for the longline fishery was the northern horse mussel. Others were the ocean quahog, Iceland scallop, blue mussel, and to a lesser extent, the cockle and softshell clam (Wiborg, 1946). Since other types of bait replaced the horse mussel in the 1950's, its fishery declined rapidly.

Harvests of the flat oyster for food probably had considerable commercial importance in some coastal areas of southern Norway before the beds were depleted in the mid-1800's. After that, methods were developed for cultivating spat in heliothermic "polls," the Norwegian name for land-locked fjords with sill depth less than the depth of pycnocline (layer between brackish surface water and saline subsurface water). However, more than 100 years of experience has produced only minimal commercial production. Apart from the former oyster fishery, harvest of mollusks for human consumption had little importance until the mid 1980's. Then, the fishery for Iceland scallop in northern areas increased rapidly, and it peaked in 1987 when 45,000 t (round weight) were harvested through the use of advanced gear. However, subsequent landings have decreased dramatically, and in 1992 the total quota for the fishery in offshore and coastal areas was only 2,500 t. Harvests of natural stocks of mollusks, except Iceland scallops, have not been regulated.

Since the early 1980's, spat of great scallop, flat oyster, Pacific oyster, Manila clam and carpet clam, *Ruditapes decussatus*, have been produced in hatcheries and nurseries, while spat of blue mussel and Iceland scallop have been produced by natural spat collection. So far, the cultivation industry in Norway, including blue mussel, oysters and scallops, is small. Cultivation of mollusks is regulated through governmental license, based on consideration of environmental impact, pollution risks, disease contamination risks, etc. Today, mollusks are not a common part of meals in Norway, but there is increasing use of some mollusks as food.

Iceland Scallop

Habitat Description

The main distribution of Iceland scallops is north of the Lofoten islands, with extensive scallop beds at Jan

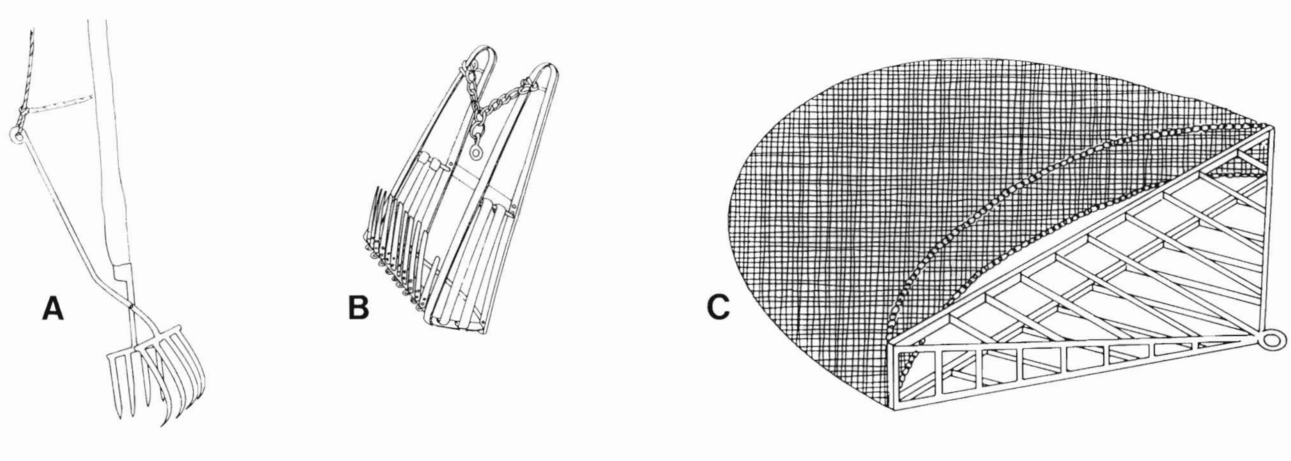

Figure 1
Typical equipment showing the historical development of harvesting gears in Norwegian mollusk fisheries. (A) Iron rake with a grab for harvesting horse mussels from shallow waters. (B) Dredge for harvesting mussels in deeper waters. The dredge is 0.8 m wide, 0.3 m high, and 1 m long (the bag is not shown). (C) Double-action dredge used in the offshore Iceland scallop fisheries. The dredge weighs 3.5 t and is about 5 m wide and 0.5 m high, and the bag which is made of iron rings is up to 6 m long.

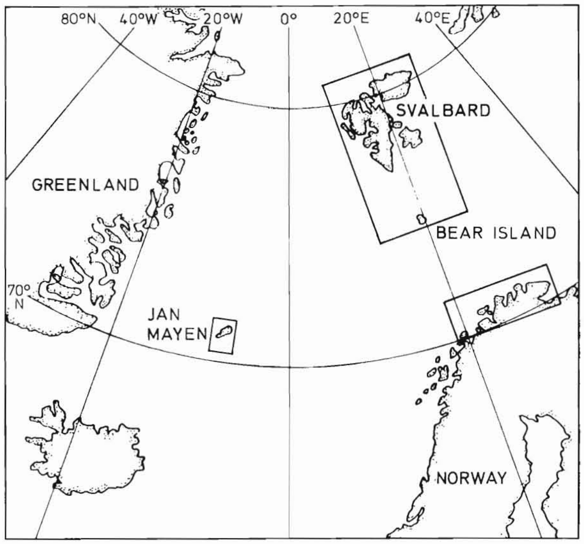

Figure 2
Areas of Iceland scallop, *Chlamys islandica*, fisheries: Jan Mayen, Svalbard, Bear Island, and coastal waters in north Norway.

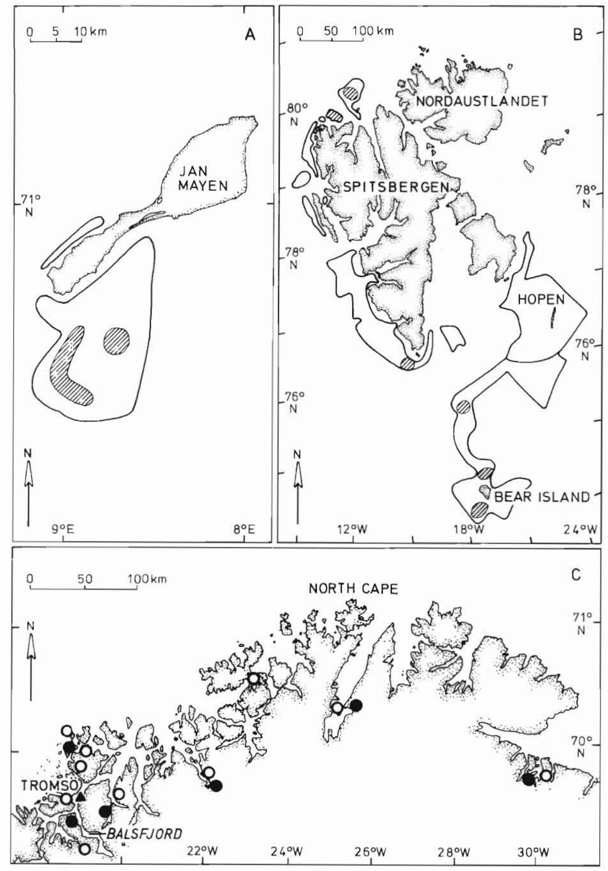

Figure 3
Scallop beds (shaded) formerly identified as beds with commercial exploitable densities (Map A), and surveyed areas (encircled) (Map B) (from Rubach and Sundet, 1989). Map C shows beds of Iceland scallops in northern Norway. Open circles show areas with empty shells and a few small living scallops (from Wiborg, 1963).

Mayen, Bear Island, and Spitsbergen (Wiborg, 1963, 1970; Wiborg et al., 1974; Sundet, 1988) (Fig. 2, 3). Along the coast of Norway from Lofoten to the Russian border, large beds occur mainly in fjords having one or more shallow sills at their entrances (Sundet, 1988; Wiborg, 1963). Iceland scallops are scarce farther south because bottom temperatures are too high, but they do occur as relict populations in the Sørgjerdfjord west of Trondheim, along the island of Tautra in the Trondheimfjord, at the entrance of Lysefjord near Stavanger, and in the Lindaspolls and the Fauskangerpoll north of Bergen (Wiborg, 1963; Greve and Samuelsen, 1970).

Along the coast of Norway the depth range of Iceland scallops is 15–60 m, at Jan Mayen and Bear Island it is 70–100 m, and at Spitsbergen it is usually 30–70 m. Iceland scallops are most abundant in localities with strong currents, and they prefer a bottom of sand, shells, and stones. Bottom temperatures of scallop banks vary considerably, from about –1.5° to 8°C in the Barents Sea, and from 4° to 10°C in coastal areas. In the fjords of Norway the salinity is usually less than 33.5‰, while on the Banks in the Barents Sea or at Jan Mayen it may reach 34.7–34.9‰ (Wiborg, 1963).

Predation on Iceland scallops by starfish, *Asterias* sp., can be substantial. In shallow coastal areas, eider ducks, *Somateria* sp., prey on them (Brun, 1971), and, north of Spitsbergen, walruses, *Odobenus rosmarus*, also prey on them. At Bear Island and Spitsbergen, barnacles, *Cirripedia* spp., are abundant and foul the shells of live scallops, but scientific surveys show that fouling does not slow the scallops' growth[1].

History of the Fishery

About a century ago, Iceland scallops were found in substantial quantities in some fjords in northern Norway (Sars, 1878; Storm, 1878–80; Sparre Schneider, 1881; Kiaer, 1906; Soot-Ryen, 1924). Exploratory fishing by the Institute of Marine Research (IMR) in Bergen

[1] Rubach, S. 1992. Finnmark Havbruksstasjon, P.O. Box 476, N-9601 Hammerfest, Norway. Personal commun.

in the 1960's and 1970's revealed that extensive scallop beds occurred at Bear Island and Spitsbergen (Wiborg, 1963, 1970; Wiborg et al., 1974). However, cost-efficient gear for harvesting scallops in offshore areas did not exist at the time. Prompted by the onset of a fishery for Iceland scallops at Jan Mayen in 1985, resource surveys were conducted by the University of Tromsø and IMR from 1986 to 1989 to assess and monitor stocks in the Barents Sea (Rubach and Sundet, 1989). Substantial areas were surveyed, and several beds with commercially-exploitable densities were mapped (Fig. 3A, B).

Table 1
Catches of Iceland scallops in metric tons (t) round weight by area for 1985–90. Meat weight is 10% of scallop weight for machine-processed scallops in the offshore areas and 14% (including gonads) for the manually shucked scallops from Troms.

	Catches (t)					
Area	1985	1986	1987	1988	1989	1990
Jan Mayen	1,192	9,085	1,621	0	1,500	500
Bear Island	0	4,042	12,227	195	0	3,269
Spitsbergen	0	1,372	30,250	13,994	4,598	2,981
Troms	0	124	849	688	760	548
Total	1,192	14,623	44,947	14,877	6,858	7,298

Table 2
Value of total landed catch (in thousands).

	Value (×1,000)					
	1985	1986	1987	1988	1989	1990
NOK	5,888	94,543	156,520	61,770	36,428	37,769
US$	920	14,777	24,456	9,562	5,692	5,901

Beginning of the Commercial Fishery

A commercial fishery in coastal areas of Troms began in 1985 (Fig. 3C). The gear and techniques were adopted from Canada, the United States, Iceland, and the Faroe Islands. Fishermen shucked the scallops on-board manually. During the off-season from March to July, many of the boats fished for cod and shrimp. An offshore fishery also began in 1985, and it increased rapidly as ocean-going ships discovered large quantities of scallops at Jan Mayen. During the first year only 3–4 vessels participated in the fishery, but effort quickly expanded, peaking at 27 vessels (one registered from abroad) during 1986 and 1987. Subsequent participation dropped to 13 vessels in 1988, 3–4 in 1989–90, and 2 vessels in 1991. The numbers of fishermen varied from about 10 to 12 on the smaller vessels to 36 on the larger ones. During 1987, total fishing effort exceeded 2,100 ship-days, ranging from 14 to 266 fishing days for individual vessels. The total annual catch in meat weight/vessel varied from 3 to 884 metric tons (t), while the daily catch exceeded 6 t for the most efficient vessels. The total catch (round weight) reached about 45,000 t with a landed value of 156,520,000 NOK (US$24,456,000) in 1987, but fell afterward and was 7,298 t with a landed value of 37,769,000 NOK (US$5,901,000) in 1990 (Tables 1, 2).

A total of 11 vessels, 10–14 m in length, were licensed for fishing in the coastal areas of northern Norway (Troms and Vesteralen) (Fig. 2), while 34 vessels participated in the offshore fishery between 1985 and 1992. Ocean-going vessels, ranging in length from 29 to 69 m, were mostly modified factory trawlers, fresh fish and shrimp trawlers, purse seiners, and longline vessels. A limited number were modified supply ships from the oil industry, while 7 vessels were contracted and specifically designed for Iceland scallop dredging. The larger of the specially designed ships cost about 100 million NOK (US$15.6 million), and typically operated 3 dredges simultaneously (Fig. 4). State-of-the-art instrumentation included geographic positioning systems, specially designed acoustic instruments and software for determining bottom type, and a computerized system controlled the dredges which kept wire tension and warp length within specified limits.

When the fishery began, the boats used a single-side action dredge (2.5 m wide) from Iceland, that was towed at 2 knots. Afterwards, catch efficiency was increased through use of a double-action dredge and higher towing speed. The dredge was a modification of U.S. and Canadian dredge types and was towed at 4–5 knots with equal efficiency on both sides (Fig. 1, 4).

Processing the Catch

At the beginning of the offshore fishery, little was known about machine processing of scallops at sea. In other countries, scallops were typically delivered to processing plants on land or shucked manually at sea. Traust Ltd. developed a pioneer automatic system for processing scallops at sea in Iceland, and, in 1985–86, it was fitted onboard the Norwegian F/V *Holberg*. The system was reasonably efficient for smooth bottoms and clean (i.e., barnacle free) scallops at Jan Mayen, but substantial, costly modifications had to be made in other areas of the Barents Sea where bottoms were rough and the

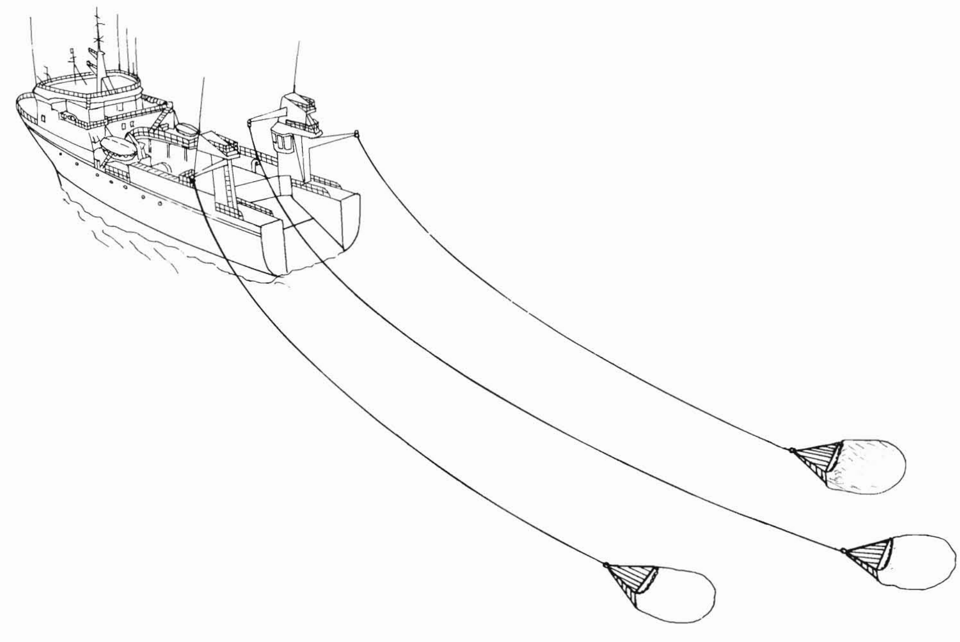

Figure 4
The F/V *Concordia*, 67 m long with 3,300 hp, a scallop dredger especially designed for the offshore Iceland scallop fishery. The vessel typically operates three dredges simultaneously.

scallops had extensive fouling. In these areas the discards of broken scallops were about 25–30% for the most efficient vessels and as high as 50% for others, resulting in substantial profit losses.

The production process has improved steadily over the years, and an efficient system, partly developed in Denmark, for sorting scallops from stones and empty shells has been installed on vessels. Processing systems similar to that developed for the F/V *Holberg* in 1985–86 were later employed by most Norwegian ocean-going scallop dredgers (Fig. 5).

Besides scallops, the catch typically consists of large amounts of stones, empty shells, and other debris which has to be discarded. The catch first goes through a rough sorting process to discard undersized scallops (<65 mm) and large stones, and then through a so-called "stone trap" where most of the trash is removed. Wear and tear on the machinery from stones, barnacles, and scallops is substantial, and the transport bands used in this part of the production line are the same type as those used in the mining industry. After discarding most of the trash, the scallops are kept in a basin of fresh water or warm (about 30°C) sea water, to relax the muscles and open the shells before they are steamed for roughly 20 seconds at 98°–100°C. The soft parts are then shaken loose from the shells and separated from them in a basin of saturated saltwater. Gonads and other soft parts are subsequently removed from the muscles. The scallops are then quick-frozen, graded by size, and then packed, usually in 10 kg boxes for export. The Iceland scallop was exported mainly to the United States until 1987–88, but since then exports to France have amounted to a substantial portion.

Production system refinements in recent years have mainly improved the sorting of trash from the scallops. In particular, a system using water under high pressure to sort out scallops early in the production line has increased productivity by effectively reducing the quantity of scallop discards. The final product weight is now 10% of the weight of whole scallops compared with 14% when scallops were shucked manually and gonads were retained.

Since 1989 the Norwegian vessel, F/V *Concordia*, a former offshore scallop dredger, has been engaged in the surf clam fishery in Canada. Norwegian and Canadian partners have transferred and adapted scallop dredging technology to the surf clam fishery.

Regulations

Inside the straight protection line along the coast of northern Norway, the government restricts fishing for Iceland scallops to 1 August–1 March. For 1985–91, the

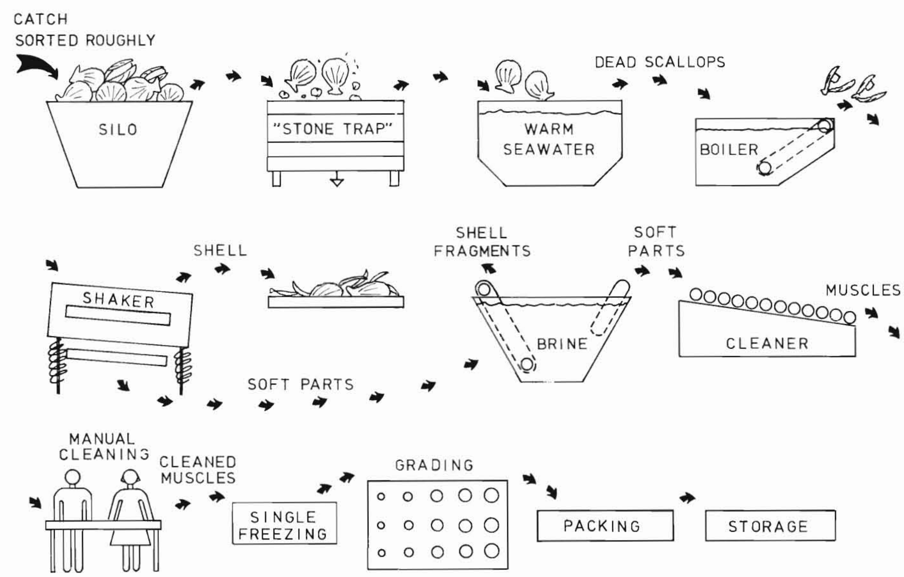

Figure 5
A typical production line on an offshore scallop dredger.

total catch quota was 600 t round weight. Since 1987, a scallop bed, "Berg feltet," south of Tromso has been closed. In 1986, bounded catch-reporting by logbooks was implemented. Fishing has been prohibited inside a protection zone extending 4 n.mi. from the coastline of Svalbard (first established in 1812 and modified by the government in 1935, 1952, and 1955). Outside this zone, no regulations were in effect for the Barents Sea scallop fishery in 1985; any registered vessel could participate. In 1986, restrictions preventing new boats from entering the fishery were implemented. Beginning in 1987, other regulations were put into effect: A lower size limit of 65 mm was introduced for all areas, and, because stocks were depleted, scallop beds were closed at Jan Mayen on 15 October. In 1989, a limited area of these beds was reopened for fishing. The total quota of 1,500 t round weight was taken by three vessels. In 1990, one vessel was allowed to do exploratory fishing in an area outside the two main scallop beds and catch a maximum of 500 t round weight. In 1989, the scallop beds at Bear Island and Moffen were closed.

Scallop Culture

Techniques for collecting Iceland scallop spat were tested successfully in Balsfjord in the beginning of the 1980's (Wallace, 1982). Thin nylon monofilaments were used as a substrate for settling larvae. In 1986–88, the University of Tromsø conducted research on artificial spat production of Iceland scallops in a laboratory-scale hatchery, but it was not successful (Wallace, 1989).

The collected spat were held in nets suspended from longline systems at depths of 2–12 m, and they grew faster and had a higher meat content than scallops held at 40 m (Wallace and Reinsnes, 1985). The market size of 60–70 mm was reached in 3–4 years, compared with 7–8 years for scallops growing in the wild. The first commercial-sized farm for culturing scallops was established near Hamarøy (lat. 68°N) in 1985. Supported by regional authorities, it was intended as a model for the development of an industry based on cultivating Iceland scallops in northern Norway. Nets, sorting equipment, and transport gear adapted for cultivation were developed to optimize production. Farms were subsequently established in coastal areas from Helgelandskysten (lat. 65°N) and northward. In 1987–89, a total of 14,000 spat collectors were set out by the farm near Hamarøy, and as many as 20,000 spat/collector bag were harvested. The spat were supplied to farms in the region. Afterward, spat production declined mainly due to insufficient methods for handling the collectors (Table 3), but higher productivity was obtained by removing spat from the collectors after 2 years instead of 1 year[2]. In 1990, the model farm was shut down due to low productivity, and farming activities along the coast declined.

[2] Aasjord, D. 1992. P.O. Box 71, N-8260 Innhavet, Norway. Personal commun.

Present Condition of the Fishery

During 1992, only one or two ocean-going ships were fishing for scallops in the Barents Sea, while 11 were licensed for scallop dredging within the Norwegian basic line, where the fishery was open between 1 August and 1 March. Its 1992 quota was 500 t round weight. Scallop beds at Bear Island were reopened for fishing from 1 September 1992 through the end of May 1993, with a total catch quota of 2,000 t round weight. The scallop bed at Moffen was reopened from 1 June 1992 to 1 January 1993.

Prognosis of the Fishery and Culture

The most substantial scallop beds have been mapped by surveys made by scientific and commercial vessels. During the 1980's, the fishery was conducted on long-established scallop beds with a large proportion of old (>10 years) scallops. The fishery is not likely to support more than 3–4 vessels on a long-term basis, due to high exploitation rates in the late 1980's and slow growth and resettlement rates of the scallops. Offshore vessels are costly, and hence large catches, often more than 2–3 t/day, are required merely to cover expenses. The fishery is self-regulating, in part, since vessels usually leave a scallop bed when the catches become marginal. Since harvesting efficiency is typically low, this generally occurs long before the beds become depleted.

The development of methods to collect spat of the Iceland scallop may lay the foundation for future commercial cultivation. The scallops would be suspended from longline systems or seeded on the bottom.

Great Scallop

Habitat Description

Great scallops occur at depths of 5–60 m in coastal waters from the southeast to the Lofoten islands (lat. 68°N), the northern limit of their natural distribution (Wiborg and Bøhle, 1974; Høisaeter, 1986). They favor bottoms of sand or a mix of sand, mud, and gravel. Densities as high as 2–3/m^2 are fairly common in some fjords along the western coast (Wiborg and Bøhle, 1974) and in coastal areas outside Trondheim[3]. In Skagerak and Kattegat, scallops occur mainly at 25–50 m. Their

[3] Monkan, A. 1992. Taro Skjell A/S, N-7190 Bessaker, Norway. Personal commun.

Table 3

Production of molluscan spat in millions. *Ostrea edulis* were produced in polls; *Crassostrea gigas, Ruditapes philippinarum, R. decussatus,* and *Pecten maximus* in hatcheries; and *Chlamys islandica* by artificial seed collection.

	Production (millions)					
	European flat oyster, *O. edulis*	Pacific oyster, *C. gigas*	Manila clam, *R. philippinarum*	Carpet shell, *R. decussatus*	Iceland scallop, *C. islandica*	Great scallop, *P. maximus*
1903–30	<0.5					
1931	1					
1932	1.5					
1933	2.1					
1934	4					
1935	5					
1929–68[1]						
1984	4[2]					
1985	6					
1986						
1987	2	3			18	
1988	6	5			8	
1989	12	5	40		5	
1990	1[3]	3	170	5		0.06
1991			70			

[1] Production statistics are not available from this period, but annual production of up to about 10 million spat in Vågstranda have been alluded.
[2] Production estimates for 1984–89 are from Vågstranda. In addition, minor quantities were produced in small breed-polls during the 1970's and 1980's.
[3] Produced by semi-intensive method in Espevikpollen (see text).

distribution is believed to be limited by hydrographical conditions, particularly variations in temperature and salinity due to the cold brackish water coming from the Baltic sea during late winter and early spring (Parsons et al., 1991).

In controlled laboratory experiments, juvenile scallops had substantially higher mortalities at low salinities (<29‰) at 5°C, a common temperature during winter, than at 10°C (Strand et al., 1993). In contrast, juveniles grown in suspended culture in a fjord on the southwestern coast had high survival during winter, when salinity dropped to as low as 25–29‰. The scallop's main predators are starfish and the edible crab, *Cancer pagurus*.

History of the Fishery

The great scallop has been of little commercial importance in Norway. Early dredging attempts yielded low returns, due mainly to rough bottoms and an abundance of seaweed that filled the dredges in only short tows (Wiborg and Bøhle, 1974). Instead, since the 1960's, scuba diving has been the most common harvesting method. The harvest by leisure diver-fishermen has probably been extensive in some areas along the coast, and, around Bergen there are signs of over-exploitation. During 1987–91, in the coastal areas outside Trondheim, divers harvested an estimated 50,000 scallops, while 100,000 (20 t round weight) were harvested in 1992 by a commercial firm[3]. Several unconfirmed reports suggest that similar quantities have been harvested along the western coast in recent decades (Wiborg and Bohle, 1974). The diver-fishermen sold them mainly to local fresh markets (restaurants and hotels). In recent years, prices have ranged from 8 to 15 NOK (US$1.20–2.00)/scallop in domestic fresh markets.

Scallop Culture

Spurred by the increasing European scallop cultivation interest in the early 1980's, the feasibility of commercial scallop culture in Norway was considered. Extensive areas along the coast might provide suitable habitat. Growth studies from western Norway suggested that scallops attain commercial size (100 mm) in 4–5 years after spawning (Strand, 1986). Collection of wild spat has been only marginally successful, as <36 spat/collector bag were collected in Sognefjorden (Hovgaard, 1983), with similarly low numbers, 30–40 spat/collector bag, being harvested in coastal waters outside Trondheim[3].

A research program at the University of Bergen during 1985–88 focused on the development of hatchery technology and cultivation methods appropriate for Norwegian waters. After promising results of spat production in a laboratory-scale hatchery, a large-scale pilot commercial hatchery was built in Øygarden, north of Bergen, in 1987 (Magnesen, 1989). The hatchery, operated by 4–5 persons, had low production during the first 2 years, mainly due to technical problems with scaling up of the laboratory production system. In 1990–91, however, there appeared to be a breakthrough. Factors crucial for producing spat, 1–3 mm long, were identified in a controlled hatchery environment (Magnesen, 1991). Large-scale production seemed feasible, but high mortality rates followed when spat were transferred to the sea. During 1988–91, a total of 60,000 spat (Table 3), 15 mm long, were produced in the hatchery, with the peak number of 25,000 in 1991. Efforts to grow spat in artificial nursery systems have not been successful (Magnesen, 1989), while use of a shallow enriched sea basin, combined with a system for manipulating salinity, fertilization, and circulation, has proven successful for the growth of juveniles only for a limited period during summer (Andersen and Naas, 1993).

The cultivation method termed "ear-hanging" involves hanging of the scallop on a vertical suspended line by a nylon string passed through a small hole drilled in the ear of its shell. Growth was faster by hanging the scallop from a nylon string cemented to the shell rather than through a hole drilled in the ear (Strand, 1991). Cement stringing may be used on smaller scallops, 20–25 mm. than the size needed for drilling a hole through the ear, 40–50 mm. The intermediate culture in nets may then be shortened, giving a more cost-efficient cultivation technique.

Present Condition of Fishery and Culture

Reliable statistics for the total harvest of great scallops by diver-fishermen along the coast do not exist; this harvest may be substantial. The commercial firms near Trondheim have been earning their incomes by harvesting wild stocks, and undersized scallops, <10 cm long, are reseeded on the beds. They have also cultivated scallops suspended on longline systems, using nets and ear-hanging. In 1993, a processing plant was established for the production of dishes on the half-shell.

A national research and development program on scallop cultivation was started in 1993. The program deals with spat production in hatcheries, intermediate culture in nets or cages, and extensive sea bed cultivation.

Outlook

Scallop abundances along the coast are too low to support a large commercial fishery. Nevertheless, regulations are probably needed to protect certain scallop beds from depletion. Substantial increases in production of the great scallop can be obtained only through aquaculture. Many areas along the coast from Stavanger to north of Trondheim appear to be highly suitable habitats for scallop farming (Strand, 1991). However, increased knowledge about environmental requirements for cultivation are needed to assess the production potential, and, since the bottom topography is generally rough, development of efficient harvest methods are needed. Methods for reducing predation on seeded spat, as well as interference with other activities in coastal waters should be addressed.

Horse Mussel

Habitat Description

Horse mussels occur along the entire coast at depths of 5–90 m, while extensive beds are found from the western coast to Northcape (Fig. 6) (Wiborg and Bohle, 1974; Høisaeter, 1986). In some regions between Bergen and Trondheim they are also abundant on tidal flats (Wiborg, 1946). Mussels are commonly attached by a byssus to hard bottom or gravel, or may be partly buried in sand, sand mixed with mud, or clay bottom. Their main predators are starfish; common whelks; dogwhelks, *Nucella lapillus*; edible crabs; wolf-fish, *Anarhichas lupus*; and eider ducks (Wiborg, 1946).

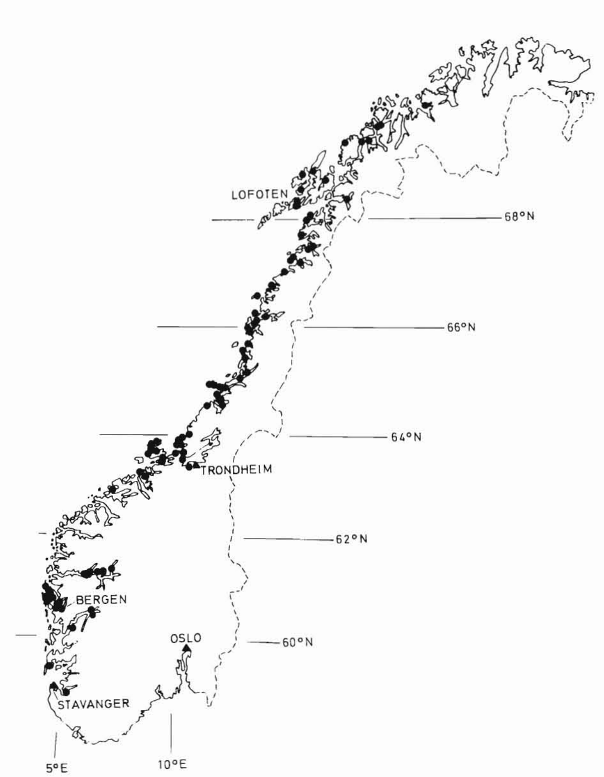

Figure 6
Locations where commercial harvests of horse mussels, *Modiolus modiolus*, have taken place (from Wiborg, 1946).

History of the Fishery

The horse mussel has been the main species in Norway's bait fishery, probably since longline fisheries began in about 1500–1600, although it was first alluded to as bait in 1770 (Bratrein, 1988). Horse mussels as bait were first mentioned in the Annual Report of Norwegian Fisheries in 1869, when commercial quantities were used in longline fisheries in Lofoten[4].

Fishermen harvested horse mussels from shallow waters using a stick with a grab which they could operate with a line (Fig. 1). Different types of sticks were developed for various depths and bottom conditions. Sticks up to 15 m long were operated from small rowboats, and fishermen usually held a water-glass between their teeth leaving their hands free to handle the stick. They brought the mussels to the surface with the stick or collected them in a net on the bottom and then hauled them to the surface. The season began between October and January and continued until March or April when spawning occurred or until the spring algal bloom reduced visibility in the water (Wiborg, 1946).

The development of dredges for use in deeper waters expanded the area where mussels could be harvested and increased the use of mussels as bait for the longline fisheries in the 1880's (Wiborg, 1946). Fishermen usually pulled the "modern" dredge (Fig. 1) by a hand winch operated from an anchored boat. Mussels were also harvested by divers, who could select preferred market sizes. However, diving operations could be limited by visibility and depth and were in most cases not profitable. Limited information is available on catch and effort for the above harvesting methods. Many mussel beds were extensively exploited and some have been wiped out by fishing (Wiborg, 1946; Bratrein, 1988). As early as 1891, government regulations were contemplated. In 1897, 1912, and 1933, various measures limiting the fishery were promoted but never implemented. Cultivation of horse mussels was considered impractical because the mussels grow too slowly (Wiborg, 1946).

The earliest harvests of horse mussels for use as bait in the longline fishery were in Lofoten and adjacent areas (Fig. 6). The mussels were sold whole and in tubs

[4] Anonymous. 1894–96. Aarsberetning vedkommende Norges Fiskerier, Lofotfiskeriet. Kristiania. Cited in Wiborg (1946).

of about 60 l each. Preservation of horse mussels with salt allowed harvests of beds at some distance from Lofoten. This practice was first mentioned in 1883[4]. In subsequent decades, use of salted mollusks as bait increased in a market which had been traditionally dominated by herring and squid. In 1888, roughly 400 t meat weight of mussels were used as bait, 9% of the total weight of bait (Bratrein, 1988). Horse mussel fisheries in the Bergen area (Fig. 6) became the most important source of bait for the longline fisheries in Lofoten. Other important bait fisheries took place in Trøndelag and Nordland. The overall annual catch from 1914 to 1951 varied from about 70 to 600 t, with a value of nearly 500,000 NOK (US$78,000) (Wiborg, 1946). The use of horse mussel as bait declined substantially in the 1950's as new technology developed to favor other baits like frozen herring and prawns, but a small harvest supplying some local fisheries has continued.

Present Condition and Prognosis of the Fishery

Diver-fishermen harvest modest quantities of horse mussels along the coast and sell them fresh or as shucked mussels in brine. Dredges, similar to those used in the former bait fishery, are used on some beds along the coast. Currently, the market for horse mussels is limited. In the future, however, it may increase and their seemingly extensive resources along the coast could be used more. Stock management should take into account lessons learned from overfishing practices in the former bait fishery along with existing biological knowledge of this species (Wiborg, 1946).

Blue Mussel

Habitat Description

The blue mussel is distributed along the entire coastline. The most extensive beds are found northward to Trondheim in sheltered areas, influenced by freshwater runoff with salinities of 20–30‰ (Wiborg and Bøhle, 1974). In the Oslofjord, they are normally found in depths down to 10 m, and along the southern coast down to 3–4 m. In outer areas of the western coast, larvae will settle on artificial substrates in the upper 0.2–0.3 m (Aase and Bjerknes, 1984). Settlement depth of larvae increases towards the fjords, and in the inner part of the Sognefjord it may reach 16 m (Hovgaard and Joranger, 1981). In fjords with high freshwater runoff, blue mussels may be absent in the upper meters, as they do not thrive in salinities <15‰. Their main predators are eider ducks, starfish, wolf-fish, dogwhelks, and the edible crab.

History of the Fishery

The only recorded landings of dredged blue mussels are from the period 1872–1912 (Bøhle, 1974). As many as 60 t/year were harvested in the Oslofjord for use as bait in the longline fishery. Harvests of blue mussels for human consumption was limited; during this period, a maximum of 2.5 t/year from the inner Oslofjord were sold in the fish market in Oslo.

Farming Mussels

In the 1960's and 1970's, interest in blue mussel cultivation increased, and toward the end of this period many farms were established. The most common cultivation method involved collecting spat in the wild on artificial substrates and growing them on suspended longline systems. A rough surface, such as ropes of polypropylene or stripped net-lines, was generally preferred as substrate (Kleppe, 1986; Hovgaard and Joranger, 1981).

Mussels were grown to market size, 50–60 mm, on the substrate on which they settled, or they were removed and put in net bags for further growth (Bøhle, 1972). Mussels grown on their settling substrate usually require thinning to obtain good growth. A yield of 5–10 kg/m of line may be obtained after 1.5–2.5 years.

In recent years, an increasing portion of the mussel supply for the fresh market has been harvested from a bottom culture operation at Fosen outside Trondheim (Fig. 6). In a bed about 0.5 hectare in size, 1–2 m deep, and with strong currents, wild mussels settled or were seeded. They are harvested from a boat, using a grab operated with a stick, and pulled to the surface by a boom. Mussels were harvested from this site in the former bait fishery.

Statistics on the number of farmers involved in blue mussel cultivation are not available from official records. The number of shellfish-farms in business has been considerably lower than the number of licenses. In 1987 about 100 farms (800 licenses) existed, but in 1990 the number fell to 20–30 farms (400 licenses). Most mussel farming has been part-time work.

As a result of the optimistic prospects for mussel cultivation in the early 1980's, several processing plants were built. A plant in Austevoll, built in 1981, had an annual production capacity of 2,500 t round weight. The main product was steamed mussels in brine. However, the mussel supply from farmers in western Norway never reached quantities needed to support a profitable business.

In the past decade, various products from 3–5 processing plants have been introduced to the market. Whole mussels, frozen in their natural juices, have been sold in 0.6 kg or 1 kg packages to Scandinavian markets. Production reached roughly 100 t in 1987, but stopped because of an insufficient supply and the diarrhetic shellfish poisoning (DSP) problem. Whole mussels have also been canned (600 g portions). Production of single-frozen mussels has recently been started in mid Norway. In the last decade, the main problem for processing plants has been lack of a mussel supply.

Cultured mussels have also been considered as food for farmed salmon and cod. They must cost fish farmers <1 NOK (US$0.15)/kg to make them economical to use. Such a low price can be obtained only through large-scale production.

The former Fish Farmer Trade Organization (FOS) had exclusive rights to trade in cultivated mollusks in Norway during 1985–91. According to statistics obtained from FOS, mussel production increased in the early 1980's, peaking at 500 t in 1985, and subsequently decreased (Table 4). However, actual production is known to be considerably higher, and, for 1989–91, estimated annual production was 300–500 t, mainly from the districts north of Trondheim. In recent years, farmers have been paid 3–5.50 NOK (US$0.50–0.90)/kg for fresh mussels and about 11 NOK (US$1.70)/kg for iced and packed mussels.

Waters affected by runoffs from manufacturing industries are closed for harvesting and cultivation of mollusks. Current knowledge on contaminants in the most affected areas are summarized in Naes et al. (1992) (organochlorines and polycyclic aromatic hydrocarbons) and Ringdal and Julshamn (1994) (heavy metals). The Hardangerfjord appears to be an ideal habitat for mussel cultivation (Kleppe, 1986). However, in 1984 mollusk harvesting and cultivation were obstructed there because quantities of heavy metals caused by runoffs from the metallurgy industry in Sorfjorden were high (Slinning et al., 1984).

Another problem is eider duck predation, which can be substantial as they have invaded farms in large numbers in many regions. Fouling of cultivated mussels by ascidians, bryozoans, hydrozoans, and seaweeds may also be immense, particularly in outer coastal areas (Kleppe, 1986).

Table 4

Production of cultivated blue mussel, *Mytilus edulis*, in metric tons (t) and oyster, *Ostrea edulis* and *Crassostrea gigas*, in thousands for 1983–91. Data for 1983–84 from Norwegian Shellfisheries Association; 1985–89 for Fish Farmer Trade Organization. Numbers estimated by the authors are given in brackets.

Year	Blue mussel (t)	Oyster (×1,000)
1983	300	300
1984	400 [600]	100
1985	500 [800]	500
1986	170	95
1987		
1988	87	96
1989	45 [500]	145
1990	[300]	
1991	[300]	

Shellfish Poisoning

Cultivation of blue mussels in Norwegian fjords has shown great potential, but for the presence of algal toxins. After 1984–85, the decline in mussel production (Table 4) was mainly a result of strict quality control to protect the public from DSP and paralytic shellfish poisoning (PSP) (Tangen, 1983; Hovgaard and Byrkjeland, 1987). The inability to control algal toxins was a limiting factor, and, in later years, DSP, and in some instances PSP, has severely hampered mussel production along the southern coast and in the fjords of western Norway. In the Sognefjord, where the conditions for mussel cultivation otherwise appeared ideal, approximately 1,000 t were discarded due to DSP in 1984. The diarrhetic shellfish toxins (DST) in mussels harvested from Sognefjorden are complex and different from DST usually found in European mussels, but resemble the profile found in Japanese scallops (Lee et al., 1988). Algae toxins are less of a problem north of Trondheim. In recent years, therefore, mussels have been produced only in the northern areas, despite slower growth (2.5 years to reach market size) compared with areas further south (1.5 years). A monitoring program on toxic phytoplankton along the coast has been conducted since 1991. In some areas it includes phytoplankton analysis and mouse test when toxic phytoplankton species are found. The Directorate of Fisheries is responsible for quality control relating to biotoxins (PSP, DSP) and chemical and bacteriological pollutants. The quantity of toxins to be tolerated, as well as methods in the use of mice for testing, have been disputed for many years.

Present Culture Status

Blue mussel cultivation, currently hampered by algal toxins, is limited to the coast outside Trondheim and northward. About 10 farms are in business, producing 10–50 t/year each. In 1991, a total of 200–300 t was produced; roughly 100 t from the bottom culture at Fosen and the rest from cultivation on suspended longlines. Two processing plants employ 4–6 persons. Production was expected to increase in 1992. Farmers have been paid about 4 NOK (US$0.60)/kg of fresh mussels processed by the plant. Bottom-cultured mussels sell for 12 NOK (US$1.80)/kg iced and packed.

Future Culture

Mussel production in Norwegian fjords could be substantially increased. However, expansion will depend on whether a system for limiting the effect of algal toxins, primarily DSP, can be developed. Reliable methods for DSP analysis and comprehensive monitoring programs need to be developed. More research on the aspects of algal toxins and their relations to bivalves is needed. Considering that 40–70% of total cost in a mussel farm is in harvesting, more cost-efficient harvesting systems are also needed. Both those and methods for suspended culture would have to be adapted to local conditions.

Adaption of the Norwegian control system on algal toxins to new standards may give rise to substantial increase in blue mussel cultivation. If a situation allows harvesting for at least 6 months/year, an increase of total production within 3–4 years to a few thousand metric tons can result (Stavøstrand, 1989). Production might increase to 10,000–20,000 t in Norwegian fjords in the next ten years.

European Flat Oyster

Habitat Description

Depletion of the oyster beds along the coast during the 1870–80's induced people to develop methods for producing and cultivating spat in the heliothermic "polls" (Matthews and Heimdal, 1980). The flat oyster now occurs mainly in polls, where temperatures may reach about 30°C during summer.

Polls are numerous along the southern and western coasts (Fig. 7). The northernmost site where the flat oyster occurs is at lat. 65°49'N (Soot-Ryen, 1951). Ancient shell piles show that oysters were abundant along the southern coast in the Stone Age (Bøhle, 1984). Today, temperatures in open coastal waters are normally too low for oysters to exist, but there are exceptions along the southeastern coast.

The main predators of flat oysters are starfish and the edible crab, as well as wolf-fish, wrass, *Labrus bimaculatus*; common whelk, and dogwhelk (Gaarder and Bjerkan, 1934). The boring sponge, *Cliona celata*, often grows in its shell. Gaarder and Bjerkan (1934) reported that *Polydora* sp. and "shell disease" (probably the fungi, *Ostracoblabe implexa*)[5] have also been observed in shells, but only on imported oysters from Holland in the 1930's.

[5] Mortensen, S. H. 1992. Institute of Marine Research, Department of Aquaculture, P.O. Box 1870 Nordnes, N-5024 Bergen, Norway. Personal commun.

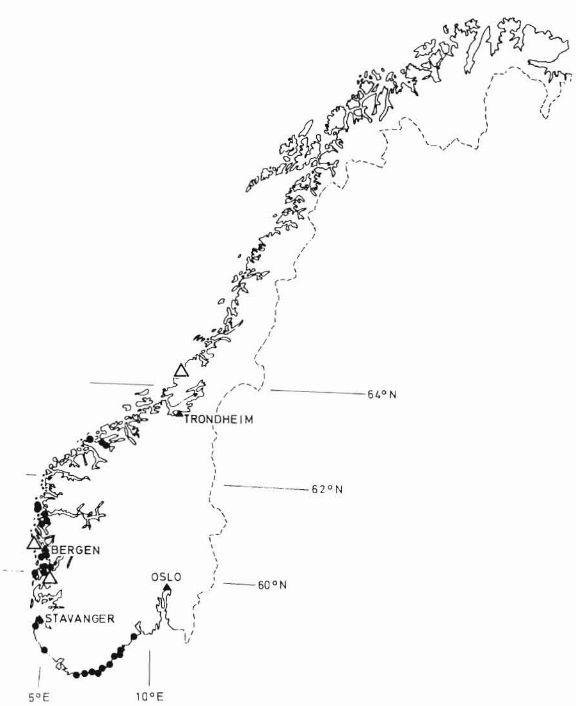

Figure 7
Locations of polls where commercial cultivation of European flat oyster, *Ostrea edulis*, has taken place (from Wollebaek, 1901; Gaarder and Sparck, 1932; Gaarder and Bjerkan, 1934; Bohle, 1984). Commercial bivalve hatchery locations are shown by open triangles.

History of the Fishery

Oysters were highly valued, and their fishery probably has had considerable commercial importance in some coastal areas. The decline in use of oysters during the Middle Ages is assumed to be attributed to a reduction of natural stocks due to climatic changes. Stocks along the western and southern coasts were harvested and exported to Denmark (Danevig, 1932). They were also preserved in pickle and exported to the Baltic area, Russia, and Belgium as late as 1750 (Helland-Hansen, 1908). Official economic reports showed that all regions south of Trondheim had oyster harvests in 1830–35, but exports were minimal (Danevig, 1932).

Little information is available on harvesting methods. A rake with a net behind was mentioned as suitable for harvesting oysters from the bottom along shores (Anonymous, 1900). A long nipper made of wood was described as harvesting equipment for collecting oysters fixed to hard bottom (Danevig, 1932), a method similar to the one used for harvesting horse mussels (Fig. 1).

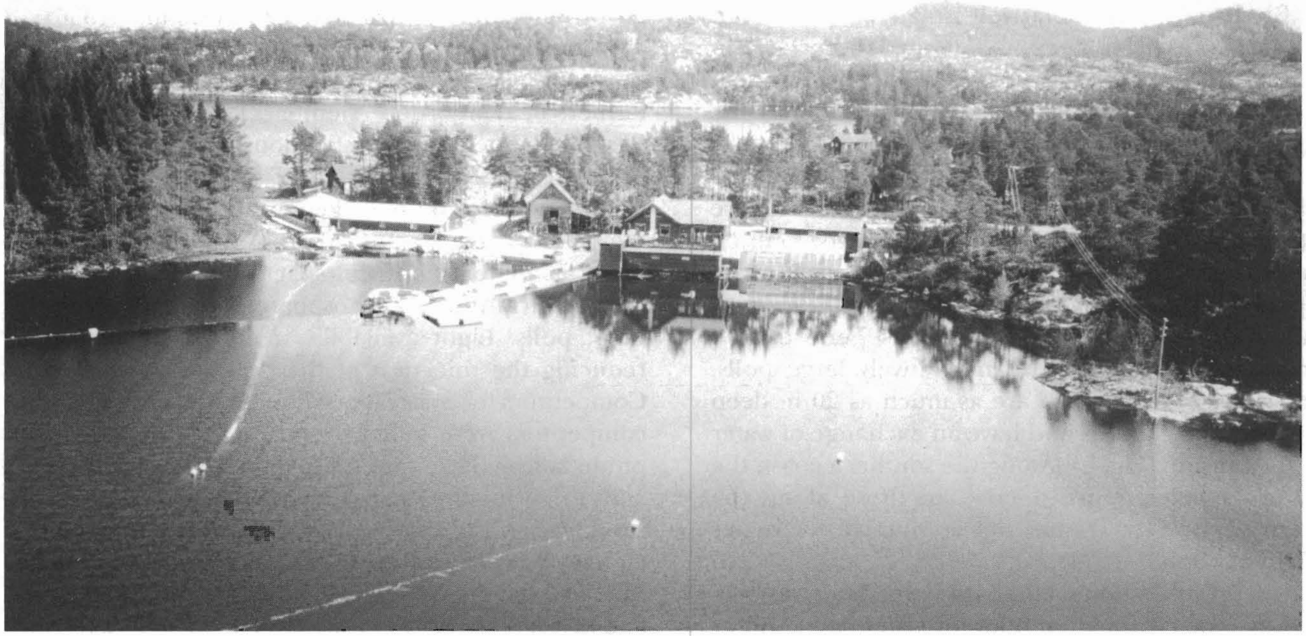

Figure 8
The Espevikpoll at Tysnes south from Bergen. The poll, 2.6 hectares in area with a maximum depth of 5 m, is seen in the foreground, the fjord in the background, and the entrance to the fjord is seen along the landbased nursery building. The hatchery is by the floating pier. (Photo: S. Mortensen).

The dramatic depletion of the stocks of oysters during the 1860–70's was believed to be due to climatic changes, resulting in oyster stocks being increasingly susceptible to exploitation and diseases (Friele, 1907; Gaarder and Bjerkan, 1934).

History of Cultivation

In 1878 Rasch (1880), who was engaged to reestablish the oyster fishery, found that several polls were inhabited by large numbers of oysters. This was attributed to high water temperatures, and he proposed to introduce the pond-culture technique known from France, Holland, and Denmark, but originally an ancient Italian method. Spat that could be produced in the coastal polls were intended for seeding on the depleted oyster beds to reestablish the commercial fishery. In 1879 the "Society for Promotion of Fisheries" in Bergen became engaged in oyster cultivation and initiated investigations of topography and hydrography in the polls, and, early in the 1880's, a considerable number of oyster companies were established with relatively high investments (Rasch, 1880; Gaarder and Sparck, 1932). Spat were also imported from Holland. The optimistic effort was temporary, however, and only two companies survived, one in the Ostravigpoll near Egersund (south of Stavanger) and one in the Espevikpoll on Tysnes (south of Bergen) (Fig. 7). The Espevikpoll has since been

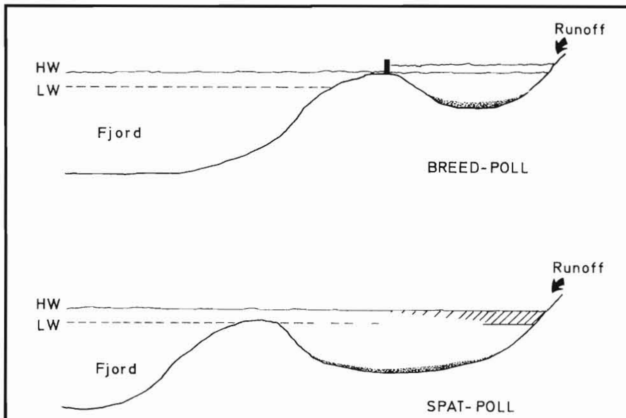

Figure 9
A schematic representation of polls used for cultivation of oyster. The breed-poll is for spat production where tidal exchange and runoff are controlled by a gate in the entrance to the outside fjord; the spat-poll is for spat grow out, where poll water is influenced by tidal exchange with the fjord.

used for mollusk cultivation almost continuously from 1882 until today (Fig. 8).

Polls used for cultivation are of two types (Gaarder and Bjerkan, 1934). Relatively small polls, termed "breed-polls," 5–10 m deep and about 1–5 hectares in area, have been used for spawning and collecting spat (Fig. 9). They have restricted water exchange over the sill or barrier and retain freshwater runoff which results in a strong salinity stratification. In polls prepared for cultivation, tidal exchanges and outflows of runoff are controlled by a gate in the entrance to the outside fjord. The vertical haline density gradient retains warm temperatures in the pools (termed heliothermic by Kirkland et al., 1983) by the "greenhouse" effect.

Spat are held for growth in relatively large polls, termed "spat-polls," which are as much as 20 m deep and 40 hectares in area and have an exchange of water with the outside (Fig. 9). Along the southern coast, the polls are smaller, more open than those along the western coast (Fig. 7), and not as suitable for oyster cultivation (Bøhle, 1984).

Advice on cultivation methods in breed-polls was published by "Society for Promotion of Fisheries" (Anonymous, 1900; Wollebaek, 1901, 1903; Helland-Hansen, 1908). Following this advice, farmers closed the entrances to the outside fjords early in spring to attain temperatures of about 20°C in May–June. They held broodstock oysters on netting suspended at a depth of 1–2 m (where temperature was highest) from a wire stretched over the polls. During June–July, when oysters spawned, farmers set out collectors made of bunched birch on wires between the oysters. The birch was suitable since the spat were easy to remove from the loose bark. In autumn the gate in the entrance was opened, allowing fjord water to enter the poll. Total renewal normally occurs during winter when the fjord water is homogenous, i.e., heavy enough to replace the bottom water in the poll. Farmers removed the spat on the collectors in April–May, almost a year after spawning. In the early years of cultivation, they grew spat at the bottom and harvested them by rakes. Later on, they cultivated them on nets suspended on a wire stretched over sounds, bays, or in spat polls. This method protected the oysters from predators, harvests were more efficient, and growth was faster.

In the early 1900's, 25–30 spat-polls were in operation, but the number declined due to a low spat supply from the breed-polls (Gaarder and Sparck, 1932). In most polls, spat production was unpredictable and commercial cultivation was difficult after years with low spat settlement. Spat production in Espevikpollen, however, failed only in 2 years from 1885 to 1900 and the poll normally produced 1 million spat/year (Anonymous, 1900). Hence, it seemed that spat production in Espevikpollen was high and stable, but production later declined and in the 1920's only minor quantities of spat were produced. According to the Annual Report of Norwegian Fisheries, published from 1879, annual oyster production never exceeded 30 t (Sømme, 1936).

In the middle 1920's, the potential of spat production in polls was again seriously considered because farmers in Limfjorden (Denmark) needed more spat. Based on intensive investigations in the Espevikpoll during 1927–29, Gaarder and Sparck (1932) gave the following advice on management of the polls. Besides temperature, which until then was considered as the main factor for successful spat production, supply of nutrients (nitrate and phosphate) were needed in the breed-polls. Light availability could be increased by reducing the thickness of the brackish surface layer. Competitors for oyster food should be reduced; benthic competitors were killed by mixing the hydrogen-sulphide bottom layer into the poll water during winter.

By following the suggestions, farmers increased their production in the early 1930's (Table 3), and, in 1934, eight polls were producing spat. One was Vagstranda in Romsdal (lat. 63°N) (Fig. 7), a poll with a depth of 10 m and about 30 hectares in size. It had the characteristics of a spat-poll. The tidal influence and the agriculture surrounding the poll presumably provided a good nutrient supply and a high production capacity compared with the small breed-polls. Cultivation of oysters began in 1929, and, from then until 1968, spat were produced from this poll and exported to Limfjorden. Annual production has been as high as 10 million spat, and total production including oysters for consumption has been as high as 80–90 t.

A minor cultivation in the small breed-polls continued until the end of the 1970's when interest in molluscan cultivation increased. At the beginning of the 1980's, 5–8 breed-polls were in operation with up to 300,000 spat/poll produced annually. Spat production was reestablished in Vagstranda in 1984 (Table 3). In 1989, production peaked at 12 million spat. In recent years, most of those produced were exported to Spain. While birch was used as spat collectors for oysters exported to Limfjorden; wood shavings were used in later years. After 1989, production was curtailed because spat failed to set and the demand for spat was low. Farmers normally lease the polls from the landowner, and since 1985 the government has required each farmer to have a license to cultivate oysters.

In the 1980's, farmers grew oysters in trays or racks of baskets suspended from longline systems in fjords. According to the former Norwegian Shellfish Farmers Association, in 1983, 75 farms were cultivating oysters. In 1986, about 12–16 million oysters (probably including imported oysters from Scotland) were being cultured (Stavøstrand, 1989), and in 1985 annual production (probably including the Pacific oyster, *Crassostrea gigas*) peaked with 500,000 oysters (Table 4).

Hatchery Culture

In Espevik and on Fosen, two hatcheries were trying to produce spat during the second half of the 1980's (Fig. 7), but commercial spat production has not succeeded. A semi-intensive spat production method in mesocosmos system, described by Naas (1991), has been shown to have promising potential for commercial production (Ø. Strand, personal commun.) (Table 3). Larvae were cultivated in plastic enclosures (7–12 m^3) placed in the Espevikpoll, where temperatures of 20°–24°C could be maintained during the summer. Natural algal blooms in the polls were used as food and renewed if necessary. Since 1988, postlarvae produced in the hatchery and the mesocosmos system have been cultivated in pumped upwelling nurseries using the Espevikpoll as a food production system (Fig. 8). In 1990, the bivalve production capacity in this cultivation system was successfully enhanced by manipulations of nutrients (total supply and composition), light availability, and stratification. Compared with the calculated natural bivalve production capacity of about 1 t live weight, 1990 production was increased sixfold (Strand, in press).

Oysters have been sold only fresh in the shell. In recent years, farmers have been paid 2–3 NOK (US$0.30–0.50)/oyster. In 1987, a station for depurating oysters was established at Harøy, western Norway. This station, with complete packing plant, was certified for oyster export to France.

Current Oyster Culture

Spat of the flat oyster is not produced commercially, probably reflecting the poor market situation in Europe. The national demand for spat is low because the possibilities for commercial oyster cultivation in Norway using existing methods are limited. A minor harvest of cultivated oysters does occur. Several farmers have begun trials of cultivating oysters in bags on shallow bottoms or on racks in shallow waters.

Future Oyster Culture

Oysters from cultivation sites in Norway have been surveyed the last few years, and *Bonamia ostreae* and other serious parasites have not been observed (Mortensen, 1992). Considering the history of the situation in Europe, where oyster production has been severely depleted by diseases, absence of serious parasites in Norwegian oyster stocks should give oyster cultivation considerable future possibilities.

Traditional methods of spat production in polls have low potential due to unpredictability and restricted production capacity. An exception may be large polls such as Vagstranda, but viable commercial production requires development of efficient cultivation methods and technology. The promising method of spat production in mesocosmos systems in heliothermic polls has great potential to produce spat at low cost. Emphasis should be given to broodstock management, food value of natural plankton during plankton succession in mesocosmos water, and efficient methods for settlement. Using polls as a food production system for bivalve nurseries has potential for future low-cost spat production.

Other Native Species

The ocean quahog is abundant in several locations on the western coast and in northern Norway. It has been commercially harvested as bait, and as many as 1,500 quahogs/day have been dredged for this use (Wiborg and Bøhle, 1974). Also, the periwinkle, common whelk, and common limpet have been considered sufficiently abundant to support small-scale fisheries (Wiborg and Bøhle, 1974). During the mid 1980's, attempts to harvest the common whelk using pots in outer Oslofjorden were not commercially successful.

In the late 1980's, spat production of the introduced Manila clam, *Ruditapes philippinarum*, encouraged cultivation trials with the carpet clam, *Ruditapes decussatus*. In 1990, the hatchery at Espevik produced spat of the carpet clam (Table 3). The queen scallop, *Chlamys opercularis*, has been considered as having potential for cultivation in many areas along the western coast where good conditions exist for natural spat collection (Hovgaard, 1986).

Introduced Species

The Pacific oyster was introduced from Scotland to the hatchery in Espevik in 1979[5], and from 1981 until 1986 farmers imported spat of this oyster from Scotland for cultivation along the Norwegian coast. However, strong restrictions were placed on the importation of mollusks for cultivation purposes in 1986 when the total number of Pacific oysters in culture was 2.5–3 million (Stavøstrand, 1989). The hatchery on Fosen produced 10 million spat in 1987–89 and an additional 6 million eyed larvae were exported to Scotland, while the hatcheries in Espevik and Øygarden produced 3 million spat annually in 1989–90 (Table 3). Considerable quantities of this production have been exported to Greece, Germany, and Ireland. The Pacific oyster grows considerably faster and survives better than the European flat oyster, particularly in mid-Norway, and, despite lower prices for it when sold, it has become the dominant cultivated oyster in that area.

The Manila clam was introduced from Scotland to Espevik and Fosen in 1987[5], and, in 1987–1988, minor quantities were produced in hatcheries there. In 1989–91, a total of 280 million spat, 1–3 mm long, were produced by the hatcheries in Espevik and in Øygarden (Table 3). The spat were cultured in pumped upwelling nurseries in Espevik and in Vagstranda, and then exported to Spain and Ireland. Production has since declined owing to low demand.

The Future of Culture

Spat of the Pacific oyster and Manila clam, and probably also the carpet shell, can be produced in large quantities in hatcheries and efficiently grown in nurseries using the polls as a food production system and thermal source. Blue mussel production may substantially increase if algal toxins are controlled. Development of efficient methods and technology in culture would probably provide possibilities for commercial production also for the native great scallop, Iceland scallop, flat oyster, and carpet shell. However, considerable market development will also be required. Great scallop, blue mussel, and flat oyster are considered as the best candidates.

The increase of salmon farming in coastal areas has introduced conflicts regarding potential molluscan farming sites, and authorities are concerned about the possible effects of substances used in fish farming on mollusk survival and growth. Mattson et al. (1988) has demonstrated the negative impact of the parasiticide, Neguvon[6], used frequently as treatment for sea-lice in salmon farming, on blue mussels and the flat oysters. Recently, the impact of antibiotics used in salmon farming on the fauna around fish farms has received attention (Samuelsen et al., 1992). Mollusks may be important carriers of fish diseases (Mortensen et al., 1992). A minimum distance of 1 km from fish farming sites is normally required for obtaining a license for mollusk cultivation.

Norwegian waters have high productivity, large sheltered areas, high water quality, and limited pollution, and bivalves at culture sites are free from the pathogens causing major culture problems in many parts of Europe[5]. The potential for increased mollusk cultivation in Norwegian waters appears to be good.

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[6] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

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Oyster and Mussel Fisheries in Denmark

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ABSTRACT

Oysters, *Ostrea edulis*, and blue mussels, *Mytilus edulis*, are the principal commercial mollusks of Denmark. From around 4000–2800 B.C., coastal natives commonly ate oysters, mussels, and cockles, *Cerastoderma edule*. Oysters later became scarcer and gastropods, mostly periwinkles, *Littorina littorea*, became important as food. For centuries, Danish kings enjoyed oysters at royal banquets. From the 16th to the 19th centuries, oysters were harvested in the Wadden Sea. During most of the last century, fishermen used a netlike tool, called a "brile" to harvest them, but in the 1870's dredges were introduced. During 1948–49, 993,387 oysters were landed, and, in the 1950's, landings were relatively high, reaching 4,000,000 oysters in the 1953–54 season. They declined afterward, and the last harvest was in 1982. In the 1970's and 1980's, Pacific oysters were imported on a small scale, and, in 1991, one farmer produced about 100,000 oysters. Before World War II, mussels were used mostly as bait for longline fishing. In the 1940's, many mussels were harvested for food. People developed a taste for them and landings have been good ever since. In 1991, landings from Limfjord alone were 109,000 t. The mussel fleet consists of 55 vessels that land mussels in 10 harbors. Most market mussels are used in the canning industry where they are boiled and put into jars or tins. Canneries pay about US$77/t for them. Fishing for cockles is new. The largest landing was 3,400 t in 1989. The molluscan fishery will remain stable during the next 5–10 years.

Introduction

Edible oysters, *Ostrea edulis*, and blue mussels, *Mytilus edulis*, are the two principal commercial shellfishes of Denmark. The shellfishing areas are the Danish Wadden Sea where salinities are about 34‰, the Limfjord where they are 23–33‰, and the Little Belt and Isefjord where they are about 17‰ (Fig. 1). Water temperatures there are around 2°C in January and 18–19°C in August, and the bottoms range from hard sand to stable silty substrates. A fishery for the cockles *Cerastoderma edule* and *C. larmarki* is relatively new.

Early Shellfishing Records

From excavations of prehistoric settlements in Denmark, we know that oysters and mussels have been on Danish menus for about 6,000 years (Madsen, 1888; Muller, 1897; Petersen, 1922; Andersen and Johansen, 1986; Petersen, 1986; Brock and Bourget, 1989; Andersen, 1989). The natives who lived along the coasts, creeks, and estuaries of Denmark (Ertebølle) from around 4000–2800 B.C. regularly ate oysters, mussels, and cockles, *Cerastoderma edule* (Andersen and Johansen, 1986; Nielsen[1]). One of the largest Danish shell mounds at Meilgaard, which is also one of the largest found in Europe, contains about 2,000 m^3 of anthropogenic wastes consisting primarily of oyster shells. For almost 400 years, oysters constituted up to about 32% of the food intake of the 40 or so natives living in Meilgaard (Petersen, 1922; Bailey, 1978).

Later, in the early Iron Age, the number of oyster shells decreased in the kitchen middens and shells of mussels, cockles, and many species of gastropods (but mostly periwinkles, *Littorina littorea*), increased. This was probably due to a change in the climate, as summers became colder in 3000–2000 B.C. and fewer oysters were available. From about 2400 B.C. until 1587 A.D., there are few or no records of oyster, mussel, and cockle shells.

[1] Nielsen, P. O. 1992. The National Museum of Denmark. The OMA-group. Personal commun.

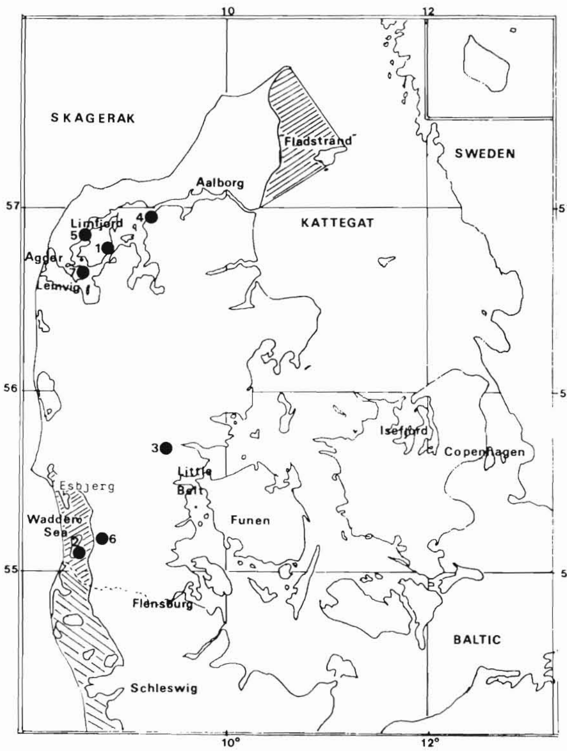

Figure 1
The areas (hatched) for the Royal (governmental) monopoly of oyster catching. The main commercial centers for selling oysters during the last three centuries in Denmark and the most important mussel fishing areas and the locations of the most important Danish mollusican industries are numbered 1–7: 1. Glyngøre Limfjord (now Abba Seafood); 2. Rømø Seafood; 3. Vejle Mussel Industry Ltd.; 4. Løgstør Mussels Industry; 5. Vilsund Mussels-Industry; 6. Dan-Shell Fish (cockle industry); 7. Jegindø Mussels.

Today, one company (in Frederiksund) mines 10,000 year-old oyster shells from deposits in the bottom of Roskilde Fjord, a small fjord next to Isefjord. The shells lie in layers several meters thick and are sold worldwide as a calcium supplement for egg-laying hens.

The Oyster Fishery

For centuries, Danish Kings considered oysters a treat at royal banquets. Almost 900 years ago, King Knud the Great brought oysters home from England and introduced them to the Wadden Sea. Later, in the Middle Ages, oysters were found in Danish waters and mentioned in the royal archives. On 21 February 1587, Frederik the Second, King of Denmark, announced that all oyster fisheries in the Kingdom were henceforth to be regarded as a royal monopoly. Only persons with royal permission were allowed to collect and sell oysters. Permissions were given primarily to the local feudal vassals (Krogh, 1870; Aaberg, 1926).

In the 16th and 17th centuries, fishermen received severe penalties if they were caught with oysters or oyster fishing gear. A third or fourth offense could mean a death sentence. Later, in the 19th and 20th centuries, local fishermen were forced to deliver all oysters fished in the Limfjord or elsewhere to the concessionary companies.

From the 16th to the 19th centuries, oysters were caught in the Wadden Sea (Fig. 1). Schleswig-Holstein (today the northern part of Germany) then belonged to the Kingdom of Denmark; thus, a greater part of the Wadden Sea area was under Danish control during this period. In the war of 1864 between Germany and Denmark, Denmark lost most of the Wadden Sea. In the 18th century, oysters caught in the Danish Wadden Sea were sold as "Flensburg Oysters," primarily in Copenhagen, but, in periods with good catches, to other parts of Europe as well. The last oysters caught in the German part of the Wadden Sea was in the 1950's (Seaman and Ruth, 1996).

Besides the Wadden Sea, oysters also occurred naturally in the Kattegat, between Skagen and the small islands known as "Hirsholmene," for nearly 200 years from 1709 to 1900. Oysters in the "Fladstrand" (Fig. 1), first harvested in 1756, occurred in deeper water (10–20 m), and were therefore difficult to harvest. They had the best quality, however, and were worth fishing. Those oysters were called "Fladstrand oysters" and were sold primarily in Copenhagen. Their annual yield was small compared with other Danish oyster fisheries; at most, only about 200,000 oysters were harvested. At an auction in 1777, the oyster banks at "Fladstrand" were leased by a single concessionary company. Later, only one, or at most only two companies leased the oyster fishery at "Fladstrand."

A contract between a concessionary company and the Danish Government dated June 1875 mentions that, between the first of September and the first of May, the King should have 30 barrels each of 500 "Fladstrand" oysters of the best quality delivered to the court. The last oysters, about 200,000, were caught at "Fladstrand" in 1895 (Anonymous, 1896; Aaberg, 1926). The royal (after 1849 the governmental) monopoly was annulled in 1982, when the last concessionary company (Limfjord Oyster Company[2]) (Fig. 1, no. 1) had to give up the monopoly due to a total failure in oyster catches over a number of years.

[2] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

The Limfjord Fishery, 1851–1982

The Limfjord, 1,575 km^2 (Fig. 1), is the largest fjord in Denmark. Oysters were found there some years after the dikes burst at Agger on 3 February 1825 allowing saltwater from the North Sea to pour in and change the salinity permanently. Before that, the Limfjord was brackish, and for centuries it had supported freshwater fisheries in its westernmost areas. In its more brackish eastern part, a substantial herring fishery existed for several centuries until it began to decline in 1825.

Oysters were discovered first at Lemvig in the western part of the Limfjord in 1851 (Fig. 1). They probably immigrated from the North Sea between 1825 and 1850. Only a few thousand oysters were found there, however, during the first 15 years after their discovery (Table 1).

In 1861, the oyster fishery was leased by the Danish Government to five different interests at an annual license fee of 885 Rd (about US$272; Rd 0.5 = ca. Dkr1 = ca. US$0.15) (Krogh, 1870) (Table 1). In 1865 the catch was 1,147,350 oysters, and, during the oyster season of 1868–69, the catch was 3,868,500 oysters worth about 67,622 Rd. (about US$20,000) (Tables 1,2) (Krogh, 1870). The license fees fishermen paid for fishing those oysters were only about 1.3% of the oysters' market price.

From 1871 to 1876, the license fee for the new concessionary company was raised to 42,000 Rd (about US$13,000), which was about 32% of the sales value of the oysters caught. Annual license fees ranged from 322 Rd in 1858–61 to Dkr 240,000 in 1878–79, while the harvests of oysters ranged from only 30,000 in 1852–53 to 7,519,030 in 1871–72 (Table 1).

From the beginning of the oyster fishery in the Limfjord in the 1850's, the government asked different officials and biologists to estimate the total standing stock and the possible quantities of oysters that could be fished in the fjord without much detrimental effect on the standing stock. Thus, for almost 100 years, the Danish Government has been advised of the stocks (Petersen, 1907, 1908, 1925; Spärck, 1924, 1925, 1927, 1928, 1929, 1932, 1949, 1950; Lund, 1942).

The first reports on investigations of the Danish oyster production, however, were written by nonbiologists. Chamberlains (Royal officers) (Eschricht, 1860; Krogh, 1870; Tonning, 1893) wrote reports on the natural oyster production in Denmark and on oyster culture from countries all over the world.

Tonning (1893) was the director of an oyster company which had permission to harvest and sell oysters from the Limfjord and the "Fladstrand" and was appointed oyster farmer by the Danish Government. Positive reports about culturing oysters in different parts of Europe, mainly France, Italy, and Holland, led in 1860 to the imports of oyster seed to Denmark, especially to the Limfjord. From 1864 to 1900, more than 12 million seed oysters (*O. edulis*) primarily from France, England, and Holland, were imported to the Limfjord (Krogh, 1870; Collin, 1884; Tonning, 1893).

In 1860 the Danish government issued a resolution that any person who wanted to grow imported seed oysters in Danish waters would need permission to do so. This permission was granted so long as the culture activity would not hinder the passage of ships and the regular fisheries in the area. Permits were given for 10 years at a time and the grower had to pay fees to the government. Six permits were issued from 1861 to 1866, and five permits were issued from 1870 to 1880. No experiments, with the exception of those in the Wadden Sea, the "Fladstrand," and the Limfjord, however, were successful.

The reason for the failure to grow oysters in Danish waters outside of the traditional areas has never been determined. Krogh (1870) believed that license fees, which the farmers had to pay the government whether or not they produced oysters to sell, were one of the main reasons for the failures in the Little Belt and some fjords in the 19th century. He wrote that it always took considerable time to produce oysters in Danish climatic conditions. Perhaps farmers should have paid fees only after they were producing oysters. Lack of knowledge about oysters' salinity requirements, food requirements, and suitable substrates for spat may also have caused the failures.

Dredging Oysters

Danish literature on the oyster fishery has little information on the fishing gear used. During the last century, oysters were caught with a netlike tool called a "brile" or "bregl" (Fig. 2A). The catching part of the "brile" was a net fastened on a wooden stick kept bent by a rope tied to the shaft. When used for catching oysters, the "brile" was without the iron sticks at the lower end. The oyster fisherman sailed over the oyster banks looking down to locate the oysters and then lowered the "brile" to catch them.

In the 1870's, dredges were introduced in the oyster fishery in the Limfjord. They consisted of a small iron-framed box with iron net and iron teeth. The dredge was more efficient than the "brile," but broke some of the oyster seed. For this reason, dredging for oysters was prohibited during some years in the late 1890's.

Fluctuation in Limfjord Yields

The number of native oysters in the Limfjord has fluctuated (Table 2) ever since the discovery of oysters there in 1851. After low production in the 1850's and early 1860's, it rose to 1,147,350 oysters in 1865–66 and peaked at 7,519,030 oysters in 1871–72. In 1885–86, however, the fishery was suspended for 5 years because production fell to only 921,825 oysters. When it began again in 1890–91, production did not increase but fell further to only 586,648 oysters. Annual production remained low until the 1910–11 season, when 3,430,000 oysters were harvested.

Table 1

The yearly yield, license fees, and names and numbers of concessionaries in the oyster fishery in the Limfjord from 1852 to 1906 (Petersen, 1907). (Dkr 1 = ca. Rd0.5 in 1875; US$1 = ca. Dkr 6.5).

Harvest year	Concessionaries	Yearly license fees	No. of oysters harvested
1852–53	Steenberg, Claudi, and Lykke (ca. US$124)	Rd 400	ca. 30,000
1853–54			
1854–55			
1855–56	The same tenants (ca. US$100)	Rd 325	ca. 86,000
1856–57			
1857–58			
1858–59	Steenberg (ca. US$100)	Rd 322	ca. 150,000
1859–60			
1860–61			
1861–62	1. Brix (ca. US$272)	Rd 885	
1862–63	2. Steenberg & Co.		
1863–64	3. Steenberg & Co.		
1864–65	4.+5. Jørgensen, Kløvberg, and Schibby		
1865–66			1,147,350
1866–67			1,207,150
1867–68			1,727,100
1868–69			3,868,500
1869–70			4,620,967
1870–71			5,343,248
1871–72	The Danish Fishmonger, Inc. (ca. US$13,000)	Rd 42,000	7,519,030
1872–73	(Paulsen and Kuhnert)		7,511,825
1873–74			7,364,765
1874–75			5,551,155
1875–76			5,933,130
1876–77	The Bank of Trade (ca. US$37,000)	Dkr 240,000	5,521,915
1877–78	(Paulsen, Kuhnert)		3,555,735
1878–79		Dkr 240,000	2,628,025
1879–80		110,000	2,875,130
1880–81		70,000	1,479,295
1881–82		111,747	2,075,990
1882–83		96,470	1,759,810
1883–84		84,000	1,319,465
1884–85			946,865
1885–86			921,825
1886–90	Preservation	Int. customs duties	No fishing
1890–91	Tonning and Teilmann-Friis	Dkr 17,599	586,648
1891–92		34,855	774,570
1892–93		29,298	871,944
1893–94		26,632	765,299
1894–95		32,264	890,572
1895–96	Tonning	Dkr 32,679	1,007,178
1896–97		33,845	1,053,828
1897–98		36,614	1,164,565
1898–99		34,709	1,088,391
1899–1900		32,349	993,968
1900–01	Brinck, Jensen, Halse, and Spellerberg	Dkr 63,591	1,009,547
1901–02		70,256	1,133,171
1902–03		63,540	1,024,840
1903–04		67,702	1,091,969
1904–05		66,257	1,068,673
1905–06		72,504	1,238,846

Table 2

The harvest of native *O. edulis* in the Limfjord from 1852 to 1937. Native and cultured oysters harvested from 1937 to 1982 (Spärck, 1949; Poulsen, 1946; Anonymous, 1955–77).

Year	No. of oysters harvested	Year	No. of oysters harvested	Year	No. of oysters harvested
1852–53	30,000	1897–98	1,164,565	1942–43	25,000 [1]55,835
1853–54	No data	1898–99	1,088,391	1943–44	45,000 [1]44,142
1854–55	No data	1899–1900	993,968	1944–45	180,000 [1]19,142
1855–56	86,000	1900–01	1,009,547	1945–46	525,000 [1]274,337
1856–57	No data	1901–02	1,133,171	1946–47	950,000 [1]162,450
1857–58	No data	1902–03	1,024,844	1947–48	1,100,000 [1]889,890
1858–59	No data	1903–04	1,091,969	1948–49	1,500,000 [1]993,387
1859–60	No data	1904–05	1,068,673	1949–50	2,400,000
1860–61	150,000	1905–06	1,238,846	1950–51	3,100,000
1861–62	No data	1906–10	annually 1,000,000	1951–52	2,600,000
1862–63	No data	1910–11	3,430,000	1952–53	3,400,000
1863–64	No data	1911–12	3,752,000	1953–54	4,000,000
1864–65	No data	1912–13	3,980,000	1954–55	3,800,000
1865–66	1,147,350	1913–14	3,950,000	1955–56	2,700,000
1866–67	1,207,150	1914–15	3,956,000	1956–57	2,300,000
1867–68	1,727,100	1915–16	5,621,737	1957–58	2,100,000
1868–69	3,868,500	1916–17	4,739,096	1958–59	1,500,000
1869–70	4,620,967	1917–18	2,465,132	1959–60	1,800,000
1870–71	5,343,248	1918–19	3,977,171	1960–61	1,100,000
1871–72	7,519,030	1919–20	4,721,972	1961–62	1,600,000
1872–73	7,511,825	1920–21	4,171,703	1962–63	1,400,000
1873–74	7,364,765	1921–22	3,372,656	1963–64	800,000
1874–75	5,551,155	1922–23	2,525,753	1964–65	200,000
1875–76	5,933,130	1923–24	1,142,177	1965–66	1,000,000
1876–77	5,521,915	1924–25	490,507	1966–67	500,000
1877–78	3,555,735	[2]1925–26	1,000,000	1967–68	700,000
1878–79	2,628,025	[2]1926–27	1,400,000	1968–69	600,000
1879–80	2,875,130	[2]1927–28	2,000,000	1969–70	[1]100,000
1880–81	1,479,295	[2]1928–29	1,600,000	1970–71	[1]400,000
1881–82	2,075,990	[2]1929–30	2,900,000	1971–72	[1]300,000
1882–83	1,759,810	[2]1930–31	4,000,000	1972–73	[1]300,000
1883–84	1,319,465	[2]1931–32	3,200,000	1973–74	[1]400,000
1884–85	946,865	[2]1932–33	1,800,000	1974–75	[1]600,000
1885–86	921,825	[2]1933–34	1,000,000	1975–76	[1]600,000
1886–90	No harvest	[2]1934–35	2,000,000	1976–77	[1]700,000
1890–91	586,648	[2]1935–36	1,300,000	1977–78	[1]500,000
1891–92	774,570	[2]1936–37	400,000	1978–81	No data
1892–93	871,944	1937–38	300,000 [1]11,475	1981–82	[1]1,000 Annul. of monopoly
1893–94	765,299	1938–39	800,000 [1]7,998	1982–91	No fishing
1894–95	890,572	1939–40	1,200,000 [1]24,053	1992	One license
1895–96	1,007,178	1940–41	100,000 [1]7,915		
1896–97	1,053,828	1941–42	100,000 [1]22,672		

[1] Number of oysters harvested from the native stock, 1938–82.

[2] No fishing on the natural stock from 1925 to 1937.

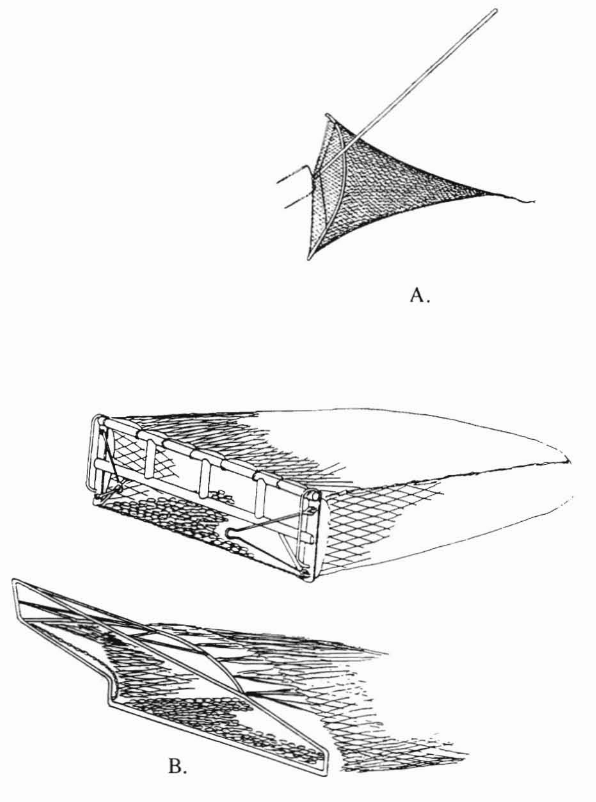

Figure 2
The different fishing gears used previously and today in the oyster and mussel fisheries in the Limfjord. A: "brile" (after Rasmussen, 1968). B: Mussel dredges "Limfjord" type; the upper one is the "old" dredge.

The first biological reports and estimates of the stocks of oysters in the Limfjord were those by Petersen (1907, 1908, 1925) and by Spärck (1928). Spärck (1928) made estimates of oyster stocks in the Limfjord in 1924 and 1927 by having divers collect oysters from three areas (Table 3). To cover larger areas than divers did, Spärck also sampled oysters over 30,000–50,000 m^2 of bottom by dredging (Table 4). In 1924, the average density was one oyster per 9.0 m^2, but by 1927 the stock density had decreased to an average of only one oyster per 60 m^2, showing a decline of 81–86% since 1924 (Table 5). Spärck (1949) estimated the total number of native oysters in the Limfjord in 1914 at about 150 million, and in 1932 it was only 15 million.

The fishing of oysters had minor effect on stock sizes (Petersen, 1925; Spärck, 1924). Spärck (1927) states that in the 1920's only about 8% of the total stock in the Limfjord was removed by fishing. At the same time, the natural mortality was around 20%.

From 1925 until about 1970, native oyster production was poor. Despite conservation measures imposed from 1925 to 1937 after the decline in catches in 1925 to only 490,507 oysters (Table 2), production did not improve when the fishery resumed in 1937. The planting of more than 15 million seed oysters from 1910 to 1925 had not helped either. Production of native oysters after the fishery resumed in 1937 was still low (i.e., between 8,000 and 55,000 oysters per year), remaining so until 1945.

To increase landings, the concessionary company imported about 170 million seed oysters from France, Holland, and Great Britain during 1924–56. Especially from Norway a large number of seed oysters were imported by train (Strand, 1996). The number of oysters produced from imported seed during 1925–37 is given in Table 2 as the difference between the number of native oysters and the total number of oysters harvested every year. The resulting production for 1937–69 was around 16 million marketable oysters, and the gain was only around 10% (Anonymous, 1955–77). The last good production of native oysters was in the middle 1970's, when about 700,000 oysters were landed. In the 1979–81 seasons, seed oysters were imported from the Seasalter hatchery in England, but subsequent harvests remained low.

The reason for fluctuations in the Limfjord oyster stocks was probably due to a number of colder summers (Spärck, 1924, 1928, 1949). Studies of other Danish oyster stocks, as well as those elsewhere in Europe, show that changes in summer water temperatures play a crucial role in fluctuations of stock sizes and production of European oysters (Spärck, 1949).

After World War II, native oyster production increased again. During 1948–49, 993,387 native oysters were landed, and, in the 1950's, landings were relatively high and reached 4,000,000 during the 1953–54 oyster season. They declined afterward, and the last harvest of native oysters in the Limfjord was in 1982 (about 1,000 oysters).

Information from fishermen on bycatches of oysters in the mussel fishery in 1991 and 1992 suggest a new good period for native oysters in the Limfjord. Although summer temperatures have not been particularly high during the last 5 years, the winters have been mild, with no ice cover, and with water temperatures around 5°C in January and February.

Predators and Competitors

In addition to low water temperatures, predators and food competitors may also limit the stock size of oysters. Sea stars, *Asterias rubens*, and crabs, *Carcinus maenas*, may destroy many young oysters, while blue mussels and ascidians probably compete with oysters for food (Spärck, 1927, 1949).

Pacific Oysters in Denmark

In addition to the imports of *O. edulis* seed to the Limfjord, Pacific oyster, *Crassostrea gigas*, seed was also

Table 3
Diver investigations of the oyster stocks at different localities in the Limfjord carried out in 1924 and 1927 (Spärck, 1928).

Locality	Local characteristics	Area invest. by diver (m²)	Size distribution (cm)	Number of oysters in 1924: Live	Number of oysters in 1924: Dead	Number of oysters in 1927: Live	Number of oysters in 1927: Dead
Flovtrup (eastern part of Limfjord)	Depth 5 m, gravel and stones		6–7	3	0	0	0
			7–8	8	3	1	0
		900	[1]8–9	15	5	1	0
			[1]9–10	17	5	3	1
			[1]10–11	6	4	3	1
			[1]11+	4	0	0	0
Hanbjerg (central western part of Limfjord)	Depth 4.8 m, gravel and stones		4–5	1	0	1	0
			5–6	3	0	0	0
		700	6–7	15	6	2	0
			7–8	37	10	9	0
			[1]8–9	55	14	8	1
			[1]9–10	51	10	12	2
			[1]10–11	27	0	6	0
			[1]11+	1	0	0	0
Oddesund (the most western part of Limfjord)	Depth 5 m, clay, gravel, and stones		5–6	2	0	0	0
			6–7	18	6	0	0
		900	7–8	31	21	4	2
			[1]8–9	40	19	5	5
			[1]9–10	38	14	7	5
			[1]10–11	10	3	2	3
			[1]11+	1	0	0	0

[1] These sizes are marketable oysters.

Table 4
Dredged investigation of the native oyster stocks in Denmark's Limfjord in 1927. Number of predators and food competitors mentioned (Spärck, 1928).

Locality	Area dredged (m²)	Total no. of oysters caught	No. of predators caught	Food competitors (mussels) (t)
Livoe (central part of Limfjord)	50,000	13	725 *A. rubens* 135 *C. maenas*	Several hundred
Riisgaard (central part of Limfjord)	35,000	30	300 *A. rubens*	Several hundred
Thisted (central part of Limfjord)	30,000	17	500 *A. rubens*	Several hundred

imported in the 19th century. However, the oysters did not reproduce. In the 1970's and 1980's, Pacific oysters were imported once more to compensate for the low supply of European oysters. They were grown on suspended longlines in the Little Belt and the Isefjord, the second largest Danish fjord, near Copenhagen (Fig. 1) (Kristensen, 1989a). Oyster growing was successful, and in 1985–86 more than 300,000 were sold in the Copenhagen fish market at an average price to the farmer of Dkr 3.90/oyster (about US$0.65). However, *C. gigas* grown in France and exported to Denmark at a price between Dkr 2–3/oyster competed strongly with the Danish produced *C. gigas*. The competition was by price and not quality. In 1991, one Danish farmer produced about 100,000 Pacific oysters for the domestic market. In the same year, a company imported about 500,000 French oysters, mainly from Brittany, to sell in Copenhagen.

The Mussel Fishery

In the Danish Wadden Sea, mussels are found intertidally as well as subtidally. In the Limfjord, they are found in 1–14 m of water and in the Little Belt and the Isefjord they are in 1–10 m of water. All mussel populations build a muddy layer between their mussel carpet

Table 5
Diver investigations of the native oysters in the Limfjord in 1924 and 1927 at the same localities and the same area investigated as in Table 3 (Spärck, 1928).

Investigation year	Locality	Stock densities: m²/oyster	Percent decline in oyster densities, 1924 to 1927
	Flovstrup	17	
1924	Hanbjerg	3.7	
	Oddesund	6.4	
	Flovstrup	112.5	85%
1927	Hanbjerg	18.4	81%
	Oddesund	50.0	86%

and the bottom. In the Wadden Sea, the layer of mud may be as thick as 50 cm.

Asterias rubens and *Carcinus maenas* are the most common associates on the mussel beds, and they are taken as bycatch in the mussel fishery. Others are barnacles, ascidians (particularly *Styela clava*), and *Crepidula* spp. which is common in some areas of the Limfjord.

Investigations on the predation and natural mortality of mussels were conducted in 1991 in the Wadden Sea (Hobo Deep) (Egerrup and Laursen, 1992). Predation from crabs was insignificant but mortality from sea stars and birds, particularly eider ducks, *Somateria mollisima*, can be high in winter. Mortality from other causes is highest during summer.

The Mussel Fleet

The Danish mussel fishing fleet consists of 55 vessels. Of these, 46 fish in the Limfjord and are registered in different harbors, such as Lemvig, Aalborg, and Thisted. Four vessels are registered in Esbjerg and one in Havneby on the island Rømø in the Wadden Sea (Fig. 1); two vessels are registered in Holbaek in the Isefjord, and two vessels are registered in the Little Belt.

In 1991, 4 vessels registered in Lemvig in the Limfjord area fished mussels in the Little Belt, and in 1991, one vessel registered in Esbjerg fished mussels in the Limfjord (Fig. 1). The vessels land mussels in more than 10 different harbors. Nykøbing Mors, the largest city on the largest island in the Limfjord, is the most important landing harbor (Fig. 1, no. 1).

Most Danish mussel fishing vessels are old rebuilt fishing vessels (Fig. 3), usually with wooden hulls and a hold in their center. They have a capacity of 15–30 t. In the Wadden Sea, old Dutch mussel dredging vessels with capacities of 60–80 t are used.

Figure 3
An old traditional Danish mussel vessel carrying around 30 t of mussels.

Normally, each mussel vessel in the Wadden Sea has a crew of two or three. In the Limfjord, each usually had only two persons, but in the last 5 years, there has been a tendency for skippers to dredge mussels alone. Many skippers state, however, that their wives often demand that they employ assistants.

Dredging Mussels

Before engines were used regularly in the fishing boats in the Limfjord, mussel fishermen may have used gear other than dredges to catch mussels. However, no information on the gears is available.

In the large mussel fishery in the 1940's, the mussel fishing gear used was a Danish-constructed dredge with a rectangular frame of 0.4×2 m (Fig. 2B). Today, this dredge is used by only a few fishermen. Instead most use the "Dutch" dredge, which causes less damage to the sea bottom and the mussels. Two types of "Dutch" dredges are used. In the Limfjord, fishermen normally use only one dredge as was required in the regulation of the mussel fishery. Therefore, the dredges are much larger than dredges used in the Wadden Sea. The "Limfjord" dredge can hold up to 1.5 t of mussels; the "Wadden Sea" dredge holds only 0.5 t. The mussel vessels in the Wadden Sea use 4 dredges at a time.

The "Limfjord" dredge is emptied like the codend of a trawl, whereas the "Wadden Sea" dredge is emptied by tilting. The dimensions of the catching frame of the two different dredges are the same (about 0.7×1.8 m).

Modern mussel vessels in the Limfjord (Fig. 4) use the same fishing technique as used in the Wadden Sea and use two dredges at a time.

In the Limfjord, fishermen set their one dredge over the starboard side of their vessels, whereas those in the Wadden Sea set two dredges on each side of their vessels. The dredges are towed by wires, 14 mm in diameter, which are let out 30–60 m, depending on the water depth and the bottom type. On soft bottoms, the dredge is equiped with an extra beam to prevent it from digging and catching mud and to ensure that only mussels are taken.

The towing speed is usually around 3.5 knots. Over dense mussel grounds, the hauling time is only about 2 minutes, whereas on sparse mussel grounds the hauling time can be up to 20 minutes. The Wadden Sea is shallow and boats can dredge mussels only about 2 hours before and after high tide.

Saving Seed Mussels

Successive generations of mussels settle on top of older ones, and thus seed are dredged up with adult mussels; seed are not separated on the vessels and are landed ashore. The mussels are sorted on land, and the seed mussels were used as fertilizer or simply discarded.

The mussel fishermen maintain that during the last 10 years more than 20,000 t of small mussels have been destroyed annually. Currently, investigations are being conducted in Limfjord to determine whether it is practical to return small mussels to the beds, and, during 1990–93, an experiment to relay the small mussels on selected bottom culture plots was underway (Kristensen, 1991).

During the sorting process, it was found that 3–8% of the mussels had their shells damaged and would probably die (Kristensen, 1991). About 98% of the small mussels with unbroken shells survive when returned to the beds during the colder periods of the year (water temperature <12°C), whereas only about 50% survive in June-September (water temperature >12°C) plantings.

Preliminary results show that the returned mussels grow to market size (i.e., >4.5 cm) within 2 years. The planted mussels also have a higher meat content (+30%) than those from the natural beds. By returning 20–25,000 t of sorted small mussels annual, yields in the Limfjord may increase by about 40,000 t. This would amount to an increased annual production of around 40% of the present fishery (Kristensen, 1993).

Any environmental problems created by returning the dead or dying mussels seem small when compared with the benefits of returning 0.5–1 billion filtering mussels to the fjord. Within a fortnight or so, the live

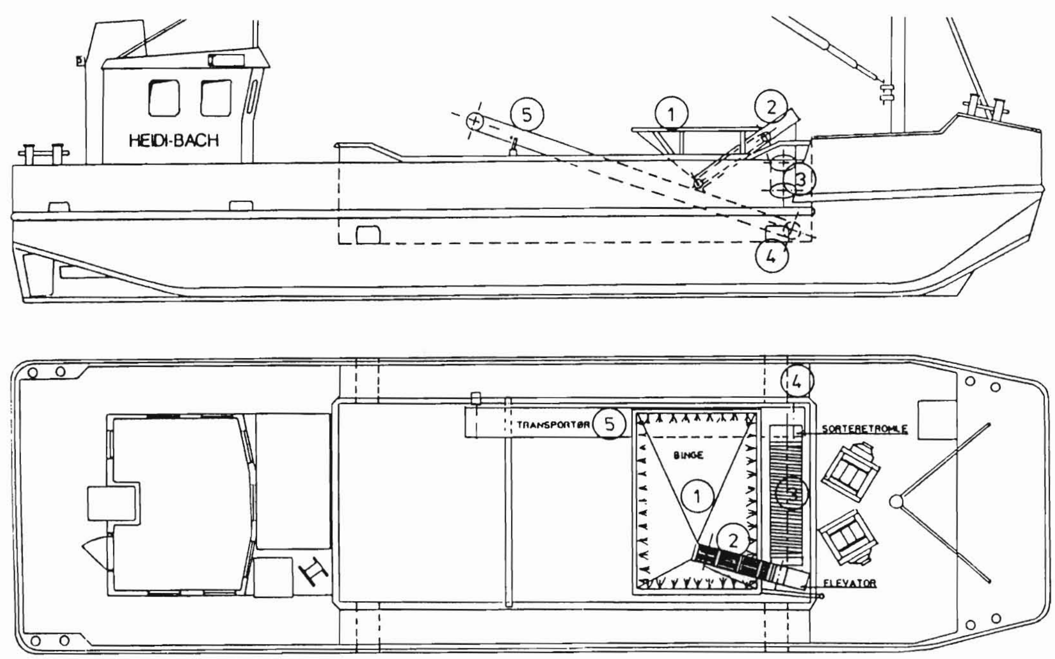

Figure 4
Technical drawing of a modern mussel vessel from the Limfjord. 1–5: Sorting system for mussels: 1. Hollow for the caught mussels; 2. Conveyor for the caught mussels; 3. Washing and sorting roller; 4. Outlet for mud and small mussels; 5. Conveyor for commercial sized mussels (Kristensen, 1991).

mussels will have ingested all the nutrients released from the decomposing of the dead mussels (Kristensen, 1991).

Fishery Regulations

The mussel fishery is under the authority of the Ministry of Fisheries and is adminstered through the law for fisheries in marine areas, "Saltvandsfiskeriloven." Those who want to fish for mussels must apply to the Ministry. The licenses are issued for 1 year and must be kept onboard the vessel all times. After use, they have to be returned to the Ministry. If a mussel fisherman wants to fish mussels somewhere else, he must apply for a license that covers the new area and return the old one.

In the Limfjord, mussel fishing is allowed only between sunrise and sunset and is not allowed on Sundays or during July. The minimum shell length for mussels that may be landed in the Limfjord is 4.5 cm; a bycatch of undersized mussels of 10% is allowed (in wet weight). Landings per vessel must not exceed 30 t per day and 100 t per week. Currently, no annual quota is established for the mussel fishery in the Limfjord. However, in the last 4 years, four areas have been closed for mussel fishing in the interest of environmental protection.

In the Limfjord, the vessel size is restricted to a GRT below 8 t and engine power must not exceed 175 HP (130 kW). Recently, legislation with respect to the number of dredges allowed in the mussel fishery in the Limfjord has been liberalized. However, most fishermen have not changed the number of dredges they use, but the newly built mussel vessels in the Limfjord use at least two dredges of the "Wadden Sea" type.

In the Wadden Sea, mussels can be dredged only between sunrise and sunset and dredging is not allowed on Fridays and Saturdays. It is also prohibited from 1 May to 15 July. Only mussels with a shell length of at least 5 cm can be landed. Again, bycatches of mussels smaller than 5 cm are, however, allowed up to an amount of 10% (in wet weight) of the catch. Fishing is allowed only in areas agreed upon with the Ministry of Environment. Each vessel is limited to a maximum of 40 t per day and 100 t per week. Annual quotas are established by the Ministry of Fisheries.

The engine power for the vessels in the Wadden Sea is restricted to 300 HP (225 kW), but there is no GRT limit. In the Isefjord and the Little Belt, engine power or GRT for vessels are not limited and there are no quotas.

Historical Production

All mussels landed are from natural stocks and are therefore limited. The Limfjord has always been the most important mussel area. Areas of minor importance are the Isefjord, the Wadden Sea, and the Little Belt (Fig. 1; Table 6).

Table 6

Danish mussel landings from 1972 to 1991. The important mussel fishing areas outside the Limfjord are the Isefjord, the Danish Wadden Sea, and the Little Belt (Kristensen, 1989a, b).

	Mussel landings (t)		
Year	Limfjord	Other Danish waters	Total
1972	24,958	5,410	30,368
1973	22,183	4,831	27,014
1974	23,571	5,165	28,736
1975	23,168	4,630	27,798
1976	30,192	7,678	37,871
1977	41,136	6,416	47,552
1978	42,000	4,756	46,756
1979	41,507	5,726	47,233
1980	55,707	[1]19,662	75,369
1981	38,207	[1]33,555	71,762
1982	44,071	[1]13,867	57,938
1983	48,879	[2]7,532	55,411
1984	49,255	[3]18,639	67,894
1985	35,853	[3]24,000	59,853
1986	63,335	[3]26,999	90,334
1987	49,496	[1,3]36,360	85,856
1988	61,766	[2]10,757	72,523
1989	68,316	[2]7,248	75,564
1990	84,955	[2]8,380	93,335
1991	108,814	[2,3]16,945	125,759

[1] Isefjord.
[2] Little Belt.
[3] Danish Wadden Sea.

The first information on Danish mussel landings from the Limfjord is from 1908 when 14 metric tons (t) of mussels were landed at a value of Dkr 1,000 (about US$11/t). Before World War II, the Danish mussel fishery was small and mussels were used primarily as bait for longline fishing in the North Sea.

In the 1940's, people in central Europe needed rich protein food. Since the fjords of occupied Denmark had large quantities of mussels rich in protein, many mussels were harvested to meet the demand. During 1942–44, more than 160,000 t of mussels were landed in the Limfjord alone (Fig. 5).

Immediately after World War II, landings fell to the prewar level. However, Europeans had developed a taste for Danish mussels, and, from 1948 to 1974, annual landings rose to between 8,800 and 22,200 t (average 17,000 t). During 1972–78, mussel landings increased once more to average 29,600 t annually (range 22,183–42,000 t). During the late 1980's and the early 1990's, mussel landings increased to their highest since World War II, and, in 1991, landings from the Limfjord

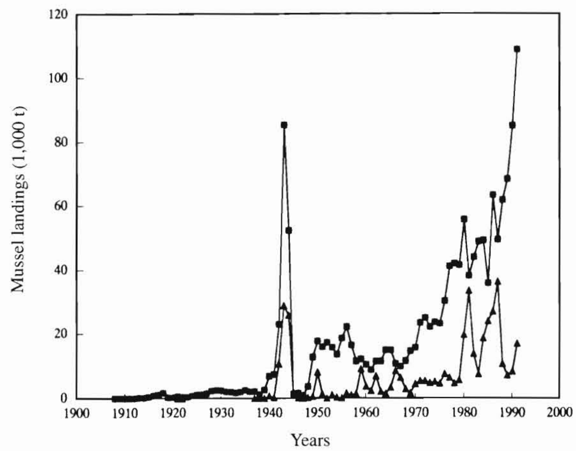

Figure 5
Net mussel landings from the Limfjord and other Danish waters from 1908 to 1991. Note: ■ = Limfjord, ▲ = Other waters (after Randløv, 1982; Kristensen, 1989b).

alone were 109,000 t (Fig. 5, Table 6). The industry credits the Ministry of Fisheries for the large increase and uses the license system to place the vessels in different mussel fishing areas.

During the 1980's, the Isefjord and the Wadden Sea had large landings. In 1980–82, landings from the Isefjord were about 55,000 t, and in 1987 about 25,000 t. From 1983 to 1987, the landings from the Wadden Sea totalled around 75,000 t. Currently, landings from the Wadden Sea are much reduced, and in 1991 they were only 5,539 t. Annual landings from the Isefjord are normally about 3,000 t while those from the Little Belt are 5,000–7,000 t.

Relative Landings and Incomes

In the 1920's and the 1930's, mussel landings constituted about 45% of the total landings of fish and mussels from the Limfjord. However, the landed value of the mussels constituted only 1–4% of the total landings (excluding oysters). Today, mussel landings constitute more than 90% of its total landings and more than 70% of their value.

In 1991, the mussel fishery in the Wadden Sea rose to a value of Dkr 15.8 million (Dkr 2.86/kg) (sold as live mussels) which command a price four times as large as those harvested in the Limfjord and marketed canned. In 1991 the total first sale value of the Danish mussels totalled about Dkr 81.8 million (US$12.6 million). Mussel fishing earnings are better than some others within the Danish fishing fleet. Danish mussel fishermen have an annual income between Dkr 1–2 million (US$150,000–300,000); this is from an annual mussel catch of between 2,000–4,000 t per vessel.

Mussel Culture Experiments

Denmark currently has few mussel culture projects. In the 1960's and later in the 1980's, several experiments were conducted. Experiments in the Wadden Sea in the 1960's were designed to culture mussels on the bottom. Local mussels and those from the Limfjord were transplanted to selected plots. Due to high mortality rates, however, the experiments were abandoned and did not lead to commercial mussel culture. The mussels transplanted from the Limfjord were unable to deal with the high densities of sand particles in the water and died (Theisen, 1968).

The success in Sweden in growing mussels on longlines led to a number of corresponding experiments in various Danish fjords (Isefjord, Mariager Fjord, Randers Fjord, and South of Funen; Fig. 1) (Kristensen, 1989a; Kristensen and Hoffmann, 1991). Municipalities, the Ministry of Fisheries, and the EEC supported groups that conducted the experiments with longline systems; later, some groups became commercial production companies (Kristensen, 1989a). Problems with ice cover, which causes damage to longlines, forced many growers to discontinue their operations (Kristensen, 1989a; Kristensen and Hoffmann, 1991), however, and only one company has "survived." The company grows mussels on longlines in Mariager Fjord for the domestic market.

Some experiments continue, for instance, in the Limfjord. Longline-grown mussels will be successful commercially, however, only if sold alive. They will never be able to compete with wild mussels that are to be canned as canneries pay only about Dkr500/t (about US$77/t) for mussels. Most Danish mussels are used in the canning industry where they are boiled and put into jars or tins. Longline growers have to obtain first-sale prices at least as high as Dkr3–4,000/t (about US$460–615/t) to realize a profit. The Danish live mussel market is limited and amounts to only a few hundred metric tons annually.

Public Health Aspects

Public health aspects for landing and sale of Danish mollusks are established in the proclamation 717 of 26 October 1990 from the Ministry of Fisheries, on public health terms for fishing, manufacture, and sale of mollusks in Denmark. Proclamation 104 of 22 March 1984 for distribution of oysters in Denmark was still in force in 1992.

The rules for heavy metals in food for human consumption are established in the proclamation from the Ministry of Environment no. 447 of 5 September 1985 and no. 612 of 16 September 1986.

The proclamations from the Ministry of Fisheries establish the number of fecal bacillus to be less than 300 cells/100 g of mussel meat or the number of *E. coli* has to be less than 230 cells/100 g of mussels for direct human consumption. The 1 January 1993 common EEC rules (91/492/EOEF) were to be established for fishing, manufacturing, and sale of mollusks in all 12 member countries.

In 1990 the voluntary supervision for toxic algae in the Danish mussel fishery failed, and a number of people got sick and got diarrhea. As a result, new and more strict supervision rules were agreed upon by the Ministry of Fisheries, the industry, and among the fishermen. The new proclamation established that mussel fishing is not allowed unless water and mussel samples have been taken the week before the beginning of the fishery. The water samples are sent for laboratory examination, where the number of potential toxic algae are registered. Mussel samples are sent to be tested for their toxic content. Mouse assay tests are used. The mouse tests are difficult to interpret, however, as the mice may die from various causes. Chemical methods are being investigated. Such methods will be better than mouse tests but are not yet refined enough to establish whether the mussels are free of toxins and safe to eat.

Supervision of DSP (diaeretic shellfish poison) is carried out all year. PSP (paralytic shellfish poison) is supervised during 1 April to 1 October, and if PSP-producing algae are observed in the water samples, the Ministry of Fisheries has to approve the results of supervision before fishing is allowed. The Limfjord has been divided into 22 subareas, and 1–2 samples from each subarea have to be examined for toxic algae and approved upon before fishing can take place.

Oysters for the fresh fish market have to be depurated for at least 7 days in recirculating UV-sterilized salt water at optimum salinity and temperatures that allow them to cleanse themselves. Before the oysters are released for sale they have to be tested for *E. coli* and for algal toxins.

The Mussel Processing Industry

Six companies buy mussels from Danish fishermen. One of these, Jegindø Mussels, exports only live mussels (in 2–4 kg plastic bags or in 25 kg jute bags) (Fig. 1, no. 7). The other five companies boil the mussels for sale. Two factories, Rømø Seafood (Fig. 1, no. 2) and Vejle Mussel Industry Ltd. (Fig. 1, no. 3), are located some distance from the Limfjord and the mussels are trucked to the factories. The industries on the Limfjord are Løgstør Mussels Industry (Fig. 1, no. 4), Vilsund Mussels-Industry (which delivers live mussels for export also) (Fig. 1, no. 5), and Abba Seafood (Fig. 1, no. 1). In the last 3 years, Swedish capital (Abba Seafood) has taken over two Danish mussel industries, Glyngøre Limfjord (Fig. 1, no. 1) and Marina, at the Limfjord.

Mussel Commodities

Danish mussels are prepared several ways for consumers. Most boiled mussels are produced as single frozen mussels for garnish in pizzas and salads. The industry produces a wide variety of types of canned, nonperishable commodities such as mussels in butter, garlic butter, spicy sauce, tomato sauce, escabeche sauce, and soya oil. Some mussels are smoked and packed in oil in tins similar to kippers.

The industry also produces perishable commodities such as mussels in water, mussels in vinegar, mussel salad with different vegetables, mussels in tomato sauce, and mussels in seafood sauce. These are sold in jars (net weight 340 g or 12 oz), tins (net weight 113–850 g or 4–30 oz), and buckets (2.4–2.7 kg or 85–95 oz). Buckets are usually sold on the wholesale market. Mussels caught in the Wadden Sea are sold primarily as live mussels and are exported.

Mussel Sales

More than 90% of the Danish mussel production is exported onto the world market at an annual value of Dkr 200–250 million (about US$30–40 million), or about 3% of the total annual Danish export of fish and fish products. In the last 1–2 years, prices of mussel meat have increased 10–30%. Thus, at present, the mussel industry is satisfied with the market situation.

Frozen Danish mussels dominate the European market (by 70%) and Danish producers compete with each other on the market. Danish canned mussels account for less than 10% of the world market. In Denmark most mussels (79%) are sold as nonperishable, perishable, or as single frozen mussels.

The Cockle Fishery

Fishing for cockles in Danish waters is relatively new. In 1980 The Danish Agency for Forest and Nature Conservation stopped the digging of lug worms, *Arenicola marina*, in the Danish Wadden Sea. In compensation, one fisherman received a 10-year license (1982–92) to fish cockles, *Cerastoderma edule* and *C. larmarki*, outside the islands in the Wadden Sea. During those 10 years, landings have varied. The largest landing, 3,400 t, was in 1989. The first sale prices of the cockles, about Dkr 25 (about US$4) per kg of meat, have been rather high during the last couple of years, while normal prices are about Dkr 11 (about US$1.70) per kg of meat. In 1992–93, the cockle fishery was restricted to only four small areas near Esbjerg, the largest city in the Danish Wadden Sea. In addition, it was allowed only in one of the four subareas for 1 year at any given time. The total permitted fishing area was restricted to only 7 km^2 which amounts to about 1% of the entire Wadden Sea.

During the last 1–2 years, fishermen have attempted to find cockles elsewhere in Danish waters but with poor results. The cockle fishery in Denmark will never reach the same magnitude of those in Holland or Great Britain. Probably, annual catches in Denmark will be between 5,000 and 10,000 t wet weight (about 1,000–2,000 t of meat).

Other Bivalve Fisheries

Other commercial bivalves in Danish waters are *Arctica islandica, Clamys opercularis,* and *Spisula solida.* They have all been fished commercially for short periods. In 1992, one fisherman in Esbjerg landed *S. solida* for the domestic market and export. His weekly landings amounted to about 25 t, and he sold them for about Dkr 5–10/kg (US$0.75–1.50/kg). The "mini clams," as they are called, are sold at the fishmonger's at a price of about Dkr 35/kg (about US$6/kg). Fishermen have never dug *Mya arenaria* commercially, although the clams are common in Danish waters.

Environmental Issues

Conflicts between the mussel fishery and the interests of environmental protection have resulted in restrictions. Mussel fishing vessels must dredge in waters at least 1.4 m deep to prevent damage to eelgrass, *Zostera marina,* beds. The Ministry of Fisheries can make exemptions on the draft rule, however, for vessels already approved for mussel fishing. In addition, large areas (about one-third) of the Danish Wadden Sea will, in the near future (1992 or 1993), be closed for human activity including fishing for mussels and cockles. The fishermen and the Ministry of Fishery have agreed to carry out a controlled fishery for mussels in the Ho Bight to investigate the role of the mussel fishery in stabilizing the biomass and production of mussels in the area.

Currently, cockle fishing is prohibited in Ramsar and bird protection areas. However, cockles may be more common there than anywhere else. Permission to fish cockles in protected areas is restricted as great consideration is given to the wildlife and birdlife in the area.

The Future of Molluscan Fisheries

The Danish mollusk fishery will likely remain stable at the current level during the next 5–10 years. Perhaps the number of vessels in the mussel fleet, particularly in the Limfjord, may increase slightly. Declines in landings from other European countries, such as Holland where mussel culture failed in 1990 and 1991, however, may result in larger landings in Denmark. Meanwhile, the industry is concerned that the demand for mussels may decline in the future as the average mussel consumer is a middle-aged male, and few young people eat mussels regularly.

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The Molluscan Fisheries of Iceland

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ABSTRACT

The Iceland scallop, *Chlamys islandica*, is the only commercially important mollusk in Iceland. Other shelled mollusks harvested for bait or food on a small scale during most of this century include *Arctica islandica, Buccinum undatum, Modiola modiolus*, and *Mytilus edulis*. Beds of Iceland scallops occur off all but the south coasts of Iceland. Most are in depths of 20–60 m. The fishery began in 1969. The total number of boats, which range in length from 10–33 m, increased from 21 to 60 during 1977 to 1985, then decreased to 31 in 1990. The average number of trips/boat/year is 65–70. Scallops are landed daily for processing the next day. The historical peak of landings was 17,068 t of meats in 1985, but was 10,000–12,400 t in 1988–91. Most scallop meats were exported to the U.S. until 1988, but since have been increasingly exported to France. A roe-on French market recently has been developing for the scallops. Minor changes are forecast in the future; landings probably will stabilize at 8–9,000 t.

Introduction

At present, the Iceland scallop, *Chlamys islandica*, is the only commercially important mollusk in Iceland, with a number of local fisheries. In 1987 an *Arctica islandica* hydraulic dredge fishery was initiated but it ceased 2 years later. Apart from that, *Arctica* has been fished for bait since around 1900, but only locally in small amounts. There is also a long tradition of fishing the European flying squid, *Todarodes sagittatus*, for bait, although catches are very intermittent in connection with the sporadic squid migrations in Icelandic waters.

Moreover, *Buccinum undatum, Modiola modiolus*, and *Mytilus edulis* have been fished on a very small scale for export and local consumption. In addition, mussels used to be collected for bait in a number of localities in the first half of the century. While this paper discusses only the Iceland scallop fishery, reported landings of all molluscan species for 1969–91 are shown in Table 1 (Anonymous, 1978–92).

The *Chlamys islandica* Fishery

Habitat Description

Beds of Iceland scallops are found along all but the south coast of Iceland. However the main distribution is rather discontinous and almost entirely limited to infjord areas (Fig. 1).

The majority of beds are characterized by a sloping topography with depths ranging from 15 to 75 m, although the greatest density of scallops is normally found in depths of 20–60 m. Substrates can vary from relatively fine sand to coarse shelly sand, often with gravel and occasional boulders (Eiríksson, 1970, 1986).

Bottom temperatures varying from –0.3° to 9.6°C have been recorded on sustainable scallop grounds. On one occasion (August 1982) a temperature of >10°C was recorded on scallop beds in Hvalfjördur, Iceland. However, results of a survey in April 1983 indicated a 65% decrease in scallop biomass in the area compared with that of the previous year, accompanied by an equivalent increase in percentage of empty shells called "cluckers." Thus, nonfishery-related mass mortalities had occurred, possibly in connection with the elevated late summer or early fall bottom temperature in 1982 (Eiríksson, 1986).

The most common large epifauna living on scallop shells are barnacles on the upper valve and tubiferous polychaetes on the lower valve. Some notable animal associates on scallop beds are various echinoderms, *Asterias rubens, Echinus esculentus, Strongylocentrotus droebachiensis*, and *Cucumaria frondosa*; the spider crab, *Hyas araneus*; and the whelk, *Buccinum undatum*. One of those, the starfish, *A. rubens*, is most likely the main

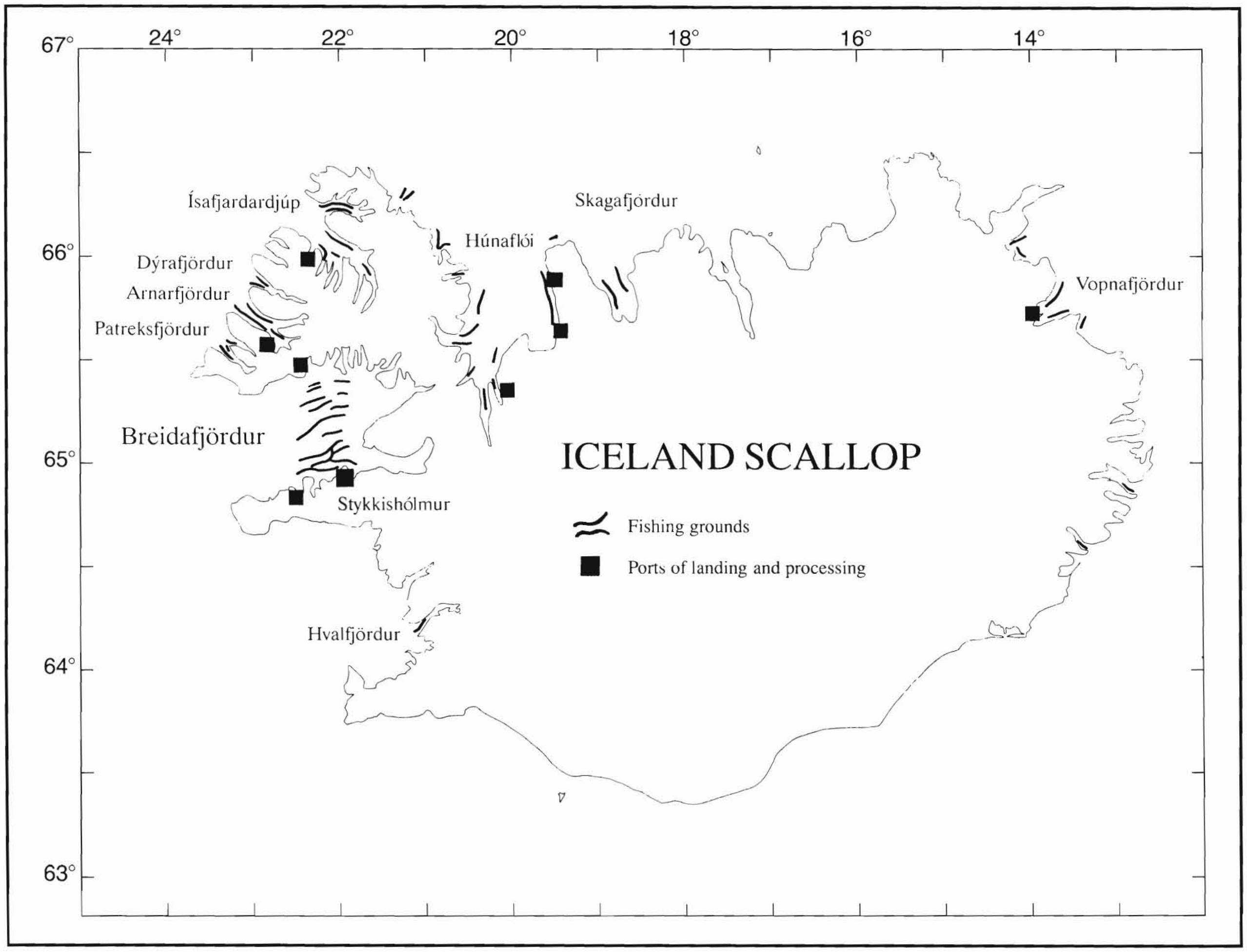

Figure 1
Scallop fishing grounds and ports in Iceland.

scallop predator, although an overall low rate of natural mortality is indicated by clucker:live-scallop ratios in catches.

History

The *C. islandica* fishery dates back to 1969. When searching for a market sample of ocean quahogs in Ísafjardardjúp in northwest Iceland in late 1968, a good catch of scallops was obtained by accident. After favorable reception of market samples in the United States, a fishery was initiated in the area in early 1969 with landings for the first year amounting to some 400 metric tons (t) live weight.

The successful initiation of the scallop fishery in Ísafjardardjúp was followed by nine dredge surveys in the years 1969–73, ranging from Hvalfjördur northward to the east coast. The surveys were led by scientific personnel from the Marine Research Institute in Reykjavík, but funded by additional parties, including grants from fisheries funds. Many beds with fishable concentrations of Iceland scallops were charted in those surveys, leading to a number of new localized fisheries, with the one starting in Breidafjördur in 1970 being the most important (Fig. 2) (Eiríksson, 1986). Thus annual scallop landings increased rapidly from 400 t in 1969 to over 7,300 t in 1972 (Fig. 3, Table 2).

The development of the fishery was halted in 1973 as the American market for scallop meats declined, which led to annual landings decreasing to only 2,800 t in 1974–75. However, during the next 10 years, landings rose steadily from 3,700 t in 1976 to the historical maximum of 17,068 t in 1985. This was largely related to the increased landings in the Breidafjördur fishery from 3,400 to 12,700 t during 1976–86.

From the peak in 1985–86, annual landings decreased again to 10,000–12,000 t in 1988–91, of which 9,000–10,000 t have been taken in the Breidafjördur area. This is partly the result of decreasing area catch quotas, but

Table 1
Reported landings (t) of molluscan species in Iceland from 1969 to 1991 (from Anonymous, 1978–92).

Year	Iceland scallop	Ocean quahog	Flying squid	Whelk
1969	402			
1970	2,432			
1971	3,658			
1972	7,349			
1973	4,848			
1974	2,851			
1975	2,784			
1976	3,669			
1977	4,427			
1978	8,719			
1979	7,800		436	
1980	9,079		16	
1981	10,186		7	
1982	12,076		13	
1983	15,181		4	
1984	15,583		1,634	
1985	17,068		2	3
1986	16,429			12
1987	13,272	1,085		
1988	10,059	4,724		
1989	10,772			
1990	12,416			
1991	10,297			

is also linked with deteriorating markets in the late 1980's (Eiríksson, 1986; Anonymous, 1978–92).

The majority of vessels fishing for scallops are involved in other fisheries, some for up to 9–10 months of the year but others for only 4–6 months. The smaller boats are mostly inshore shrimpers in winter, but they fish for demersal species in spring to summer. The larger boats, especially those of the Breidafjördur fishery, go gill netting for cod during March–May and inshore and offshore shrimping in the summer.

Since the beginning of the scallop fisheries around 1970, the boats in the northwestern fjord fisheries have been small, mostly shrimp trawlers, ranging in length from 10 to 15 m. However, in recent years this fleet is more typified by 10–20 m (15–50 GRT) boats, with a crew of 2–4 and fishing with one dredge of 1.5–2.4 m width. In the larger Breidafjördur fishery in West Iceland, the size of boats has ranged from 15–25 m (20–100 GRT, averaging 58 GRT) in 1972 increasing to 15–33 m (20–165 GRT, averaging 90 GRT) in 1990. The Breidafjördur fleet is composed of multipurpose trawler/gill net boats with a crew of 4–7 and one 1.5–2.7 m dredge, depending on size of boat. From 1977 to 1985 the total number of boats in the scallop fisheries increased from 21 to 60 but decreased again to 31 in 1990. At the same time the average size of scallop boats increased from 53 GRT in 1977 to 70 GRT in 1990 (Anonymous, 1978–92).

Most vessels in the scallop fisheries have been equipped with the wheelhouse aft, but rigged to tow the dredge from the stern and haul it in on the side (Fig. 4a, b). In the first years (1969–71) an Icelandic box-type dredge was used, resembling in some ways hydraulic clam dredges. It consisted of a rigid metal frame, a steel blade and box-shaped container that was emptied by opening the rear end. In 1972 two types of overall more effective dredges were introduced from Britain: The Manx Blake dredge and the Conolly roller dredge. The use of the Blake-type dredge became widespread in 1972–73, although it has been greatly modified and strengthened over the years, especially in connection with the rapid expansion of the Breidafjördur fishery (Eiríksson, 1986).

The present Breidafjördur dredge has similar ranges in width as the British prototypes, but it is up to three times heavier (800–1,000 kg). The frame is of heavy-gauge steel, and it has two runners connected horizontally, including a rigorous stone guard in the center. Instead of a fishing blade that was used in the Icelandic box-type dredge, the modern dredge has a relatively heavy chain ground rope in front of a metal ring belly. A heavy metal tail bar is attached to the rear of the ring belly and netting which forms the bag of the dredge (Fig. 5).

An additional Icelandic dredge has also become popular since around the mid 1980's, particularly in the Ísafjardardjúp and Hunafloi area. It is equipped to fish on both sides, and with its rolling bar and chain ground rope this dredge slides more easily over larger stones and boulders.

In all the fisheries, scallops are landed daily for processing the next day. Thus, in a typical week, the scallop boats are making five daily trips from Sunday through Thursday. Although some boats have been making 100–150 trips annually, the average number has been 65–70 trips a year in 1985–90. The fisheries are mainly seasonal during August–February, and landings in April–July are generally at a minimum. However in 1991–92 there was an increasing fishery in April–May in connection with a relatively recent scallop roe-on market in France.

In the early years of the fishery, the catch was emptied on top of large sorting tables on deck and sorted by hand. However, the hand-sorting process tended to be time-consuming owing to many undersized animals being taken along with a lot of trash. Therefore, stainless steel rotary sorter/washers, introduced in the 1970's, became widespread by the early 1980's.

Scallops are mostly landed in 300–500 kg containers or sometimes bags for machine shucking and processing the next day. Most of the production is in the form

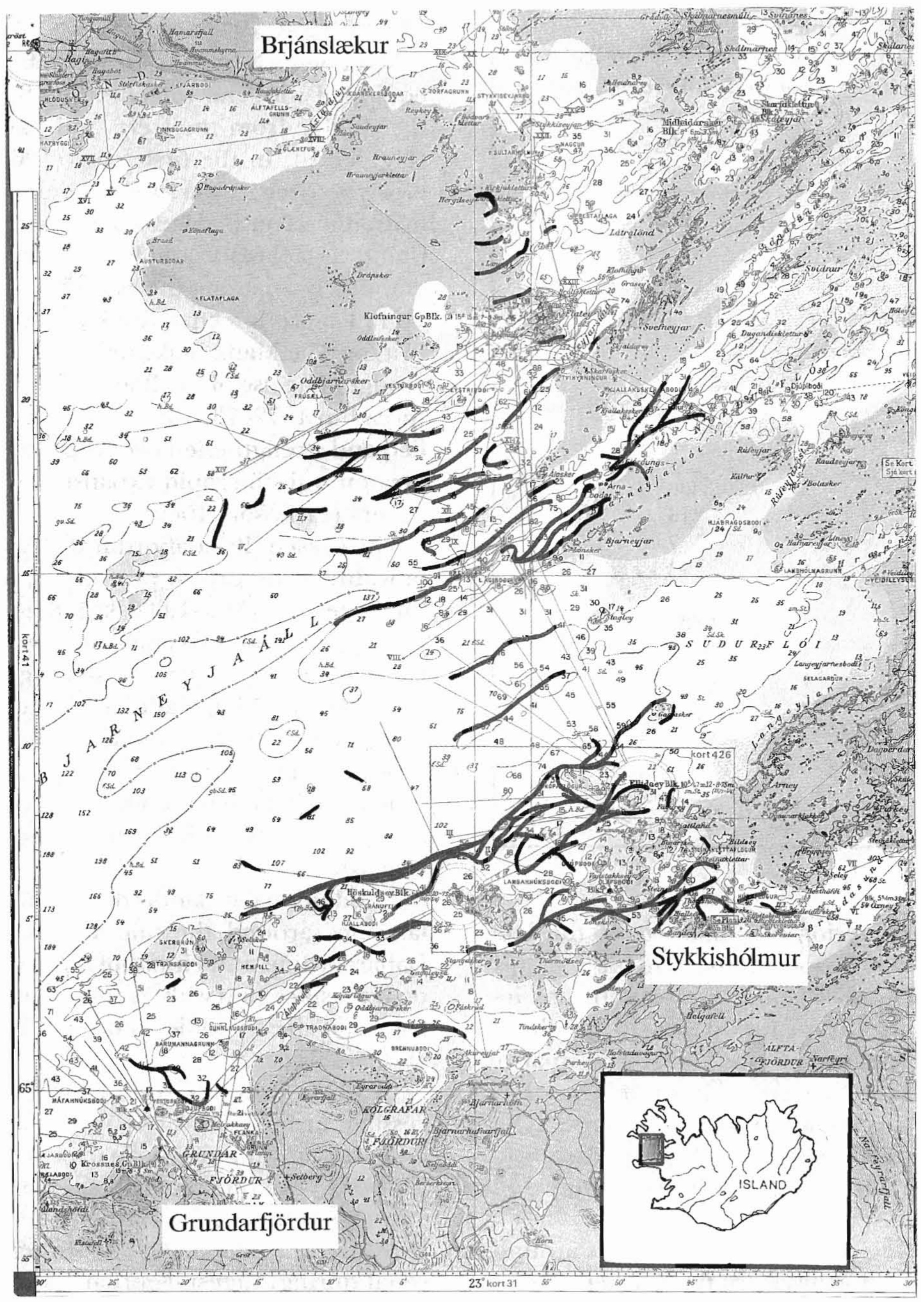

Figure 2
Detailed chart of major scallop beds in Breidafjördur.

of scallop muscles (meats) that have been separated from the viscera by cleaning machines, whose mechanism is based on a series of counter-rotating rollers. The scallop meats are fine-trimmed manually, mechanically size-graded, and individually quick-frozen in blast freezers. The yield of Iceland scallop muscle averages 10–12%, but fluctuations are considerable by areas or seasons or both. Scallop meats were mostly exported to the United States until 1988, after which they were increasingly exported to France. Recently, a roe-on French market has developed for Iceland scallops which involves increased manual handling following mechanical shucking. This production increases the yield up to about 15–18%. Figure 6 gives the annual production of scallop meats and the export value in U.S. dollars during 1969–91. The production reached a maximum of 1,840 t in 1985, and the value of exports peaked at US$14.1 million in 1986. However, taking all Icelandic marine exports, the proportion of scallops was highest in 1983 and 1972 at 2.5% and 2.3%, respectively, but

Table 2
Nominal catch (t) by areas and overall, 1969–91, of Iceland scallops (from Anonymous, 1992).

Year	Breidafjördur	Hvalfjördur	Patreksfjördur	Arnarfjördur	Dýrafjördur	Ísafjardardjúp	Húnaflói	Skagafjördur	Vopnafjördur	Overall
1969						420				402
1970	2,216					199	17			2,432
1971	2,542		68	140		534	374			3,658
1972	4,564		78	295	19	2,087	306			7,349
1973	3,218		140	196	3	1,219	72			4,848
1974	2,851									2,851
1975	2,729		28	27						2,784
1976	3,420			148			101			3,669
1977	3,752			73		260	342			4,427
1978	7,575		17	126	128	603	270			8,719
1979	6,055		16	178	141	473	937			7,800
1980	7,133	42		279	155	615	855			9,079
1981	8,328	315	32	522	74	687	228			10,186
1982	10,034	521	27	670	123	634	67			12,076
1983	11,218	346	59	842	100	921	1,695			15,181
1984	11,880	82	67	550	28	867	1,733	376		15,583
1985	12,128		16	754	120	881	1,986	665	518	17,068
1986	12,708			619	121	707	1,232	513	529	16,429
1987	11,071			227	84	314	1,576			13,272
1988	9,810				30	219				10,059
1989	10,066				60	469	177			10,772
1990	10,090			299	124	704	1,199			12,416
1991	8,918			339		346	597		98	10,298

has decreased to around 1% in 1990–91 (Anonymous, 1978–92).

As a rule, scallop processing plants are located at ports of landing. Stykkishólmur, at the western bay of Breidafjördur, is by far the most important scallop port, with frozen scallop meats accounting for about 55% of the value of marine products in 1990. Other important scallop ports are Grundarfjördur and Brjánslækur (also in the Breidafjördur area), Bíldudalur (at Arnarfjördur), Ísafjördur (at Ísafjardardjúp), and Hvammstangi, Blönduós and Skagaströnd in the Húnaflói area.

Catch per unit of effort (CPUE = landings per hour of fishing) has been monitored by logbook catch reports since late 1972. In Breidafjördur, where catch rates have generally been high, dredge tows are often limited to only 5–10 minutes, averaging 4 tows per hour. However, tows of 20–30 minutes are quite regular, especially in the smaller fjord fisheries.

Due to improved gear efficiency and the introduction of sorting machines, the average catch per hour in the Breidafjördur fishery increased from 500–600 kg in 1972–74 to around 1,000 kg in 1981–83. Moreover, the average catch per hour has since remained in or around 950 kg (Fig. 7). However, if adjustments are made according to some known changes in dredge efficiency,

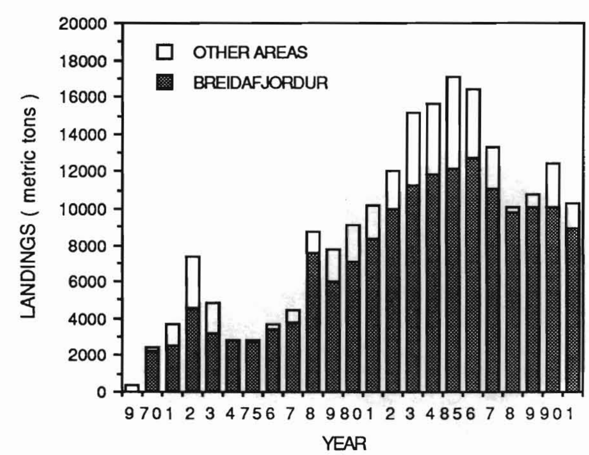

Figure 3
Landings of Iceland scallops from Breidafjördur and other areas in 1969–91.

the CPUE has decreased from around 1,300 kg in 1981–83 to some 950 kg during 1988–91. A similar trend has been observed in the smaller fjord fisheries, although a

b

Figure 4

Fishing for Iceland scallops in Breidafjördur. a. View from pilothouse of vessel showing dredge being landed; three other scallop dredge boats are in view. b. View from bow of vessel showing dredge about to be emptied. At right, note rotary sorter/washer and three crewmen culling scallops.

Figure 5
A 500 kg catch of live scallops taken in a 1.5 m Breidafjördur dredge during a research survey.

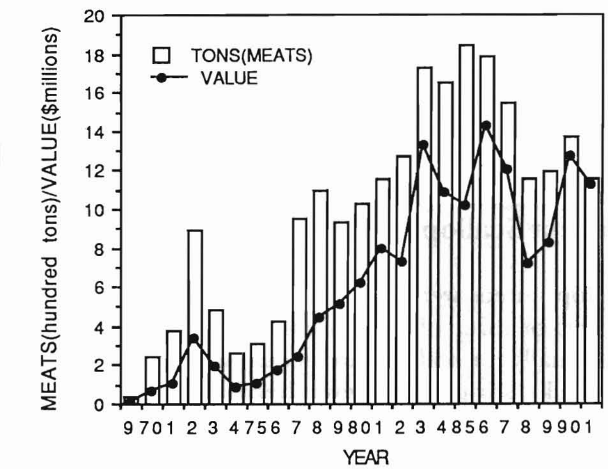

Figure 6
Annual production of scallop meats (×100 t) and export value (millions of U.S. dollars) during 1969–91.

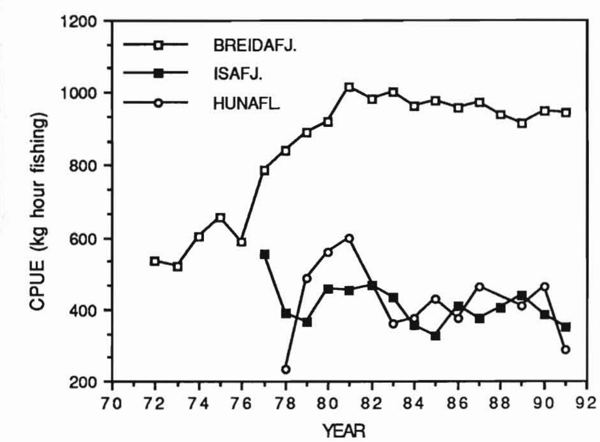

Figure 7
CPUE (kg landed per hour fishing) in Breidafjördur, Ísafjördur, and Húnaflói 1972–91.

the catch rates are lower due to either less density of scallops or smaller boats and gear (Anonymous, 1992).

Scallop Management

The rapid expansion of the scallop fisheries following the discovery of widespread beds in the early 1970's led to early catch limitations by late 1972. First, entry into the fisheries was limited to local fishing boats, and log books were made compulsory for monitoring the fisheries. By 1976 the number of processing plants was limited by the Ministry of Fisheries, which allocated a catch quota to each licensed plant in accordance with the total allowable catch (TAC) of each local fishery. Since 1984 a government management system has been enforced based on individual boat quotas for all major demersal, pelagic, and invertebrate species, including the Iceland scallop.

The government management scheme became particularly effective during the rapid development of the large Breidafjördur fishery in the late 1970's and early 1980's. At the same time, the scallop stock in the area has been monitored by an annual dredge survey in addition to the use of CPUE data from skipper's catch reports. Moreover, those two data sets have formed the basis of an annual TAC recommendation by the Marine Research Institute. As a rule, this management plan has been effective and maintained high enough catch rates for a profitable fishery in this area. On the other hand, the smaller fisheries have shown a much greater volatility, fluctuating or even discontinuing in phase with the market situation each time.

Scallop meats are regularly inspected by the Icelandic Fisheries Laboratories. Over 100 batches were inspected in 1991, including 400 bacteriological samples (personal commun.).

Current Scallop Status

Scallop quotas were allocated to 38 boats in 1991. All but two or three of these are multipurpose vessels fishing equally for scallops, demersal species (i.e. cod and haddock), shrimps, and even herring. The boats range in size from 10 to 20 m in the smaller fjord fisheries in northwest Iceland to the considerably larger 15–33 m vessels in the most important fishery at Breidafjördur. Most of the fleet has been built within about the last 30 years, with the older boats having, as a rule, been well maintained or even largely rebuilt in later years (Table 3) (Anonymous, 1990). Crew size varies according to size of boat, from 2 to 7, but most often from 3 to 6.

The annual 1991 quota per boat varied from as little as 45 t live weight and up to 750 t. However, the present management system allows for an interchangeability or transfer of quotas between boats. A typical daily catch in Breidafjördur varies from 4 to 8 t, and catch per hour from 600 to 1,200 kg, depending on size of boat, dredge, and crew. In the smaller fisheries of northwestern Iceland, the catch per hour is more typically 300–500 kg with daily landings of 3–4 t.

All the reported Icelandic scallop production is exported. In 1991, France was the largest market with 88% of Iceland's scallop exports followed by the United States.

Present government management regulations are based on total allowable catch (TAC) for each fishery. Each area TAC is set annually for the quota year 1 Sept.–31 Aug., and allocated to a limited entry of local boats, based on their average landings in a number of years previous to the individual boat quota system. Other regulations include a minimum landing size of 6 cm (shell diameter) in all fisheries and closed areas according size of boats in the Breidafjördur fishery.

Monitoring the stocks is made possible by compulsory catch reports, stating daily catch, fishing hours, and size of boat, dredge, crew, fishing area, and subarea. The logbook data along with an annual dredge survey of 120 standardized tows, are used for the annual TAC recommendation by the Marine Research Institue for the Breidafjördur area, but regular surveys are biennial or less often in the smaller fisheries.

In 1990, scallop landings amounted to 12,400 t at a landed value of US$5.5 million. At the same time some 1,366 t of meats were exported, for a total value of $12.7 million. From 1990 to 1991, the price per kg of landed whole scallops rose from $0.44 to $0.51, which meant that in spite of total landings dropping to 10,300 t in 1991, the overall landed value remained relatively stable at $5.3 million. Moreover, although exported scallop meat production in 1991 decreased to 1,160 t at $11.3 million, the price per kg of meats went up by some $0.40 over the previous year, to $9.69 (Anonymous, 1978–92).

Table 3

Length (m) and age of the Icelandic scallop fleet in 1991–92 (from Anonymous, 1990).

Length (m)	No. of boats	Building year	No. of boats
10–14	13	1945–54	2
15–19	4	1955–64	10
20–24	6	1965–74	16
25–29	12	1975–84	2
30–34	3	1985–	8

The Future

The TAC recommended by the Marine Research Institute for the Breidafjördur fishery in the quota year 1 Sept. 1992–31 Aug. 1993 amounts to 8,500 t. This is an unchanged TAC from the previous quota year, but considerably lower than the highest recommended TAC's for this area of 11,000 t in 1983–85 and 1987. Although the abundance of larger scallops (over 8 cm) decreased during the 1980's, the proportion of medium scallops (7–8 cm) has stabilized since about 1988. Also, recruitment of 5.5–6.5 cm individuals has appeared well above average in 1991–92 (Anonymous, 1992). However, major changes are not forecast in scallop quotas in this area over the next 10 years and landings will probably stabilize at 8,000–9,000 t.

The present TAC for the smaller fjord fisheries combined was set at 2,850 t for the quota year 1991–92, whereas the recommended TAC for the quota year 1992–93 stood at 3,000 t (Anonymous, 1992). Thus, the overall scope for increasing the scallop fishery appears rather limited, and total annual scallop landings are expected to remain at 10,000–12,000 t in the future.

At present, the possibility of unknown inshore scallop grounds is considered remote, although some smaller beds may still be unknown or not utilized. Furthermore, no potential offshore stocks have been located in Icelandic waters. Therefore, the scope for increasing the fishery may lie in developing the scallop fishing gear to improve its efficiency and reduce shell breakage and indirect fishing mortality.

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The History of the Queen Scallop Fishery of the Faroe Islands

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ABSTRACT

The queen scallop, *Chlamys opercularis*, is the only commercially important mollusk around the Faroe Islands. The scallop beds are close to shore, about 15 n.mi. from land. The fishery for the scallops began in 1970 with older fishing vessels being modified for scalloping. At the same time, a processing plant was constructed. The trend in catches has been increasing. In 1970–77, 4–9 ships dredged for scallops, but as inshore beds were overfished several boats left the fishery. In 1978–87, from 2 to 5 ships comprised the fleet, and in 1988–91 only one ship was fishing on the scallop beds. Nearly all scallop production is exported. Its value increased throughout the period to nearly US$6 million in 1990, but was US$3 million in 1991. In most of the period, nearly all the production went to the U.S., but since 1988 increasingly more has been exported to France.

Introduction

Situated between Scotland and Iceland, the Faroe Islands (Fig. 1) are surrounded by the relatively warm waters of the Northeast Atlantic Current with a mean water temperature ranging from 6°C in February to 10°C in August. Though different bivalves and gastropods are fished for bait and limited local consumption, these catches are small and not recorded. The exception is the queen scallop, *Chlamys opercularis*, which remains the only commercially exploited species (Fig. 2). It is dredged on the Faroe Plateau which constitutes the northwesternmost distribution of this species in Europe. Some small-scale rearing of the blue mussel, *Mytilus edulis*, has been attempted in sheltered areas recently, but no serious production or sale has sprung from it, and this enterprise has stopped now.

Queen Scallop Habitat and Fishing Areas

The queen scallop beds are situated relatively close to shore, about 1–15 n.mi. from land, on sandy, rocky, or soft bottom in depths of 30–60 fathoms with a total area of about 400 km^2 (Fig. 1). The dominant cohabitants in the main habitat of the scallop are different species of whelks, *Buccinum undatum*, *Neptunea despecta*; mussels, *Astarte elliptica*, *Venus faciata*, *Cardium echinatum*, *Modiola modiolus*, *Artica islandica*, *Venerupis rhomboides*; starfishes, *Asteria rubens*, *Henricia* sp., *Hippasteria phrygiana*, *Crossaster papposus*; brittlestars, *Ophiopholis aculeata*, *Ophiotrix fragilis*; sea urchins, *Strongylocentrotus droebachiensis*, *Echinus esculentus*; sea anemones, *Tealia felina*; hydroids, *Abietinaria abietina*, *Hydrellinaria falcata*; and hermit crabs, *Pagurus bernhardus*. The main fishing grounds lie east of the islands, but in 1988 a new area was discovered north of the islands. The development of the fishery in the two areas will be treated separately.

Fishery Development

The queen scallop fishery was spurred by the development in the Scottish scallop fishery which, after a decline in catches of the great scallop, *Pecten maximus*, in the late 1960's, turned to the somewhat smaller queen scallop. Communications with Scottish fishermen and information from Faroes fisheries biologists suggested the possibilities for a future scallop fishery in the Faroes.

When fishing began in December 1970, older fishing vessels were modified for the scallop fishery (Fig. 3). At the same time, a processing plant was constructed. After the first year of fishing, it became obvious that the adductor muscle of the scallop was largest in the autumn, and the fishing season was voluntarily set from August to January. The scallops are shocked in a processing plant (Fig. 4), at first by hand but later the process has gradually become more automated.

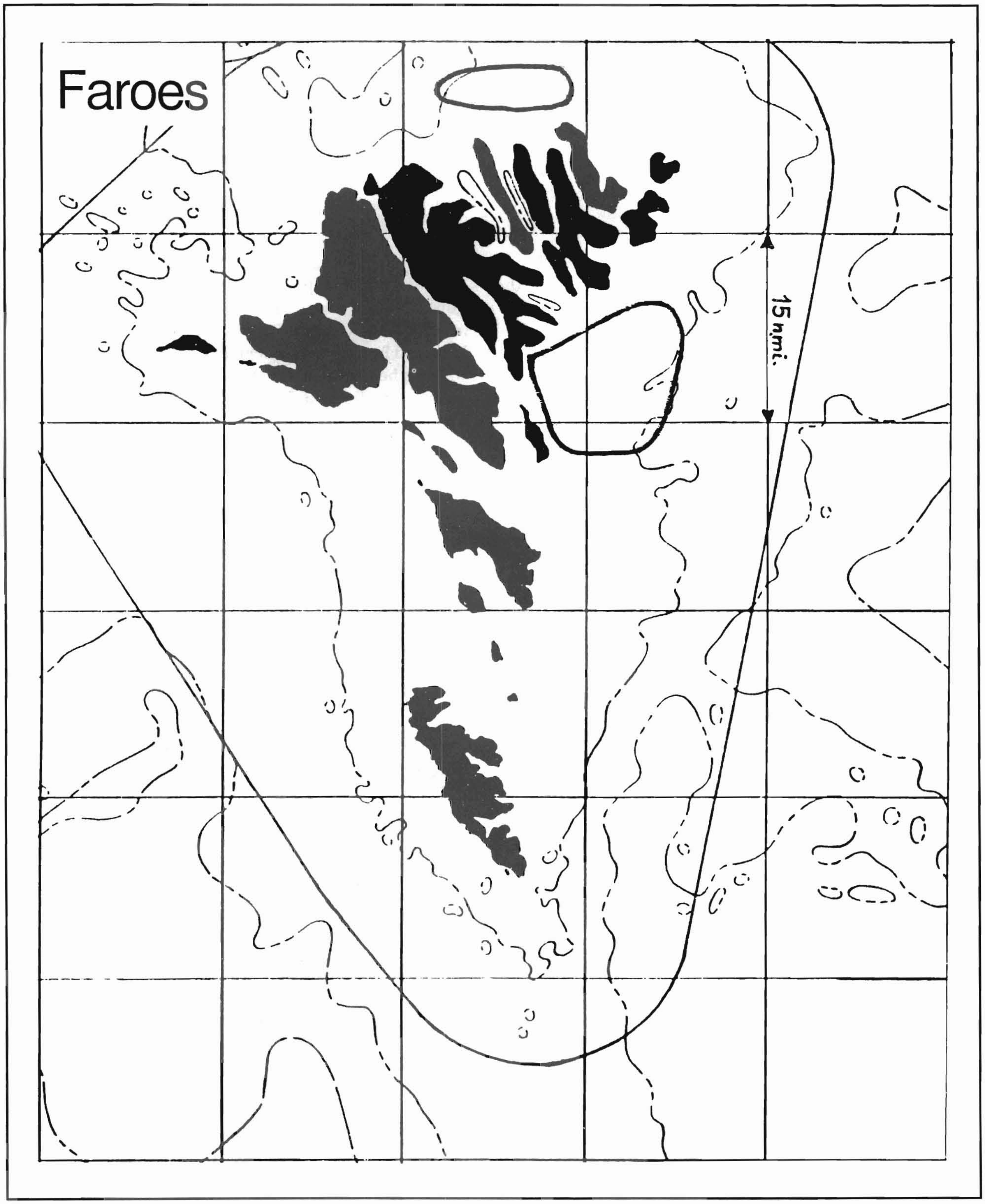

Figure 1
Map of the Faroe Islands (shaded), distribution of scallop beds (heavy outlines), and depth contour lines.

The main trend in catches and catch per unit of effort (CPUE) in units of catch (kg/foot/hour) per dredge width in feet per hour the vessel spent on the fishing grounds, has been increasing throughout the more than two decades of scallop fishing (Fig. 5). The increase in catches follows the slow but constant improvement in ships, gears, and fishing skills, as well as a gradual extension of the fishing area from time to time.

The trend in catches can be described for three main periods. During 1970–77 the catches were stable at around 500 metric tons (t) of whole scallops per year. In 1978–87 the catches stabilized at a new level of

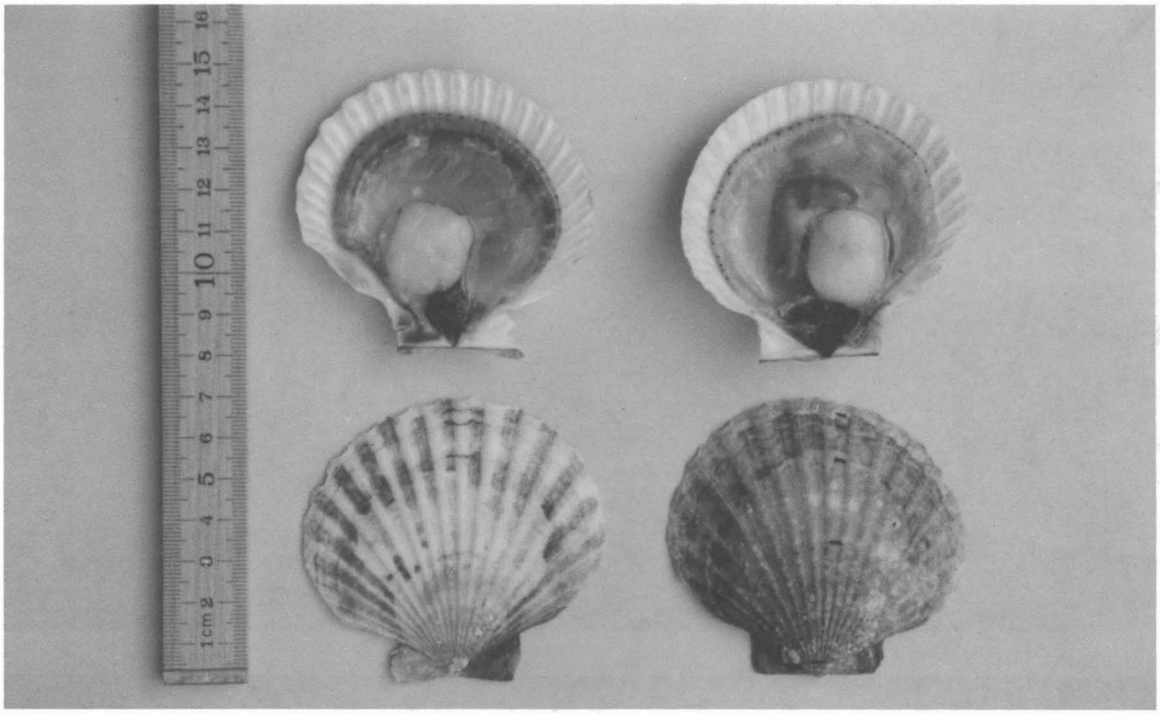

Figure 2
The outside and inside of the queen scallop.

Figure 3
An older fishing vessel used for dredging scallops.

Figure 4
Top photo, the first processing plant for the queen scallop at Oyri on the island of Streymoy. Below is the present scallop plant at the same site.

around 1,900 t. The period 1988–91 has been unstable, with increasing catches from around 2,000 t to 4,000 t. Most of the increase can be attributed to factors such as learning skills and technological improvements, but, especially for the third period, time spent on the fishing grounds has increased as well.

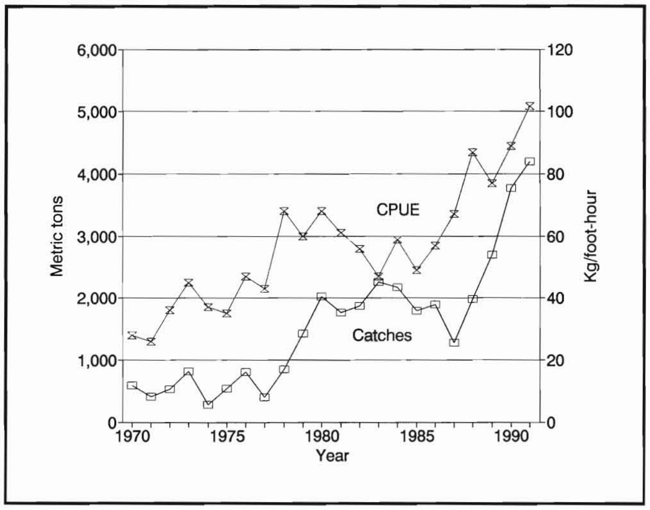

Figure 5
Catches and CPUE of the queen scallop, east of the Faroe Islands, in the period 1970–1991.

In 1970–77, the CPUE increased from the initial level of about 27 kg/foot/hour to about 41 kg/foot/hour. In this period, fishing was carried out by 4–9 ships (17–80 BRT) with 3–6 crew members. The vessels used one dredge 3–9 feet wide. The gear was light and wires thin. Usual length of wire out when fishing has been 3–5 times the depth. The towing speed was 2–3 n.mi./hour.

At first, fishing went on mostly in a limited area close to the islands, but as these beds were overfished several boats left this fishery and the ones that stayed had to search for new grounds. The series of maps (with year number) show a circulation between the subareas as some beds were depleted by fishing and others are growing new stocks. The legend shows the percentage of catch taken in each subarea (Fig. 6).

The scallop vessels usually remained at sea for a day and had about 2 hours of sailing time to the harbor and used another few hours to unload. In this period, the undersized shells (less than 55 mm high) that had to be thrown back into the sea, had to be sorted by hand (Fig. 7). As piles of shells were sorted, the fishing operation stopped for a while, and this delayed the actual fishing somewhat. Around 1973 an automatic sorting machine was installed in some boats and this increased the number of hauls per day. In 1975 some vessels shifted to thicker wire and this increased the efficiency considerably. In 1978 the CPUE went up dramatically to about 69 kg/foot/hour.

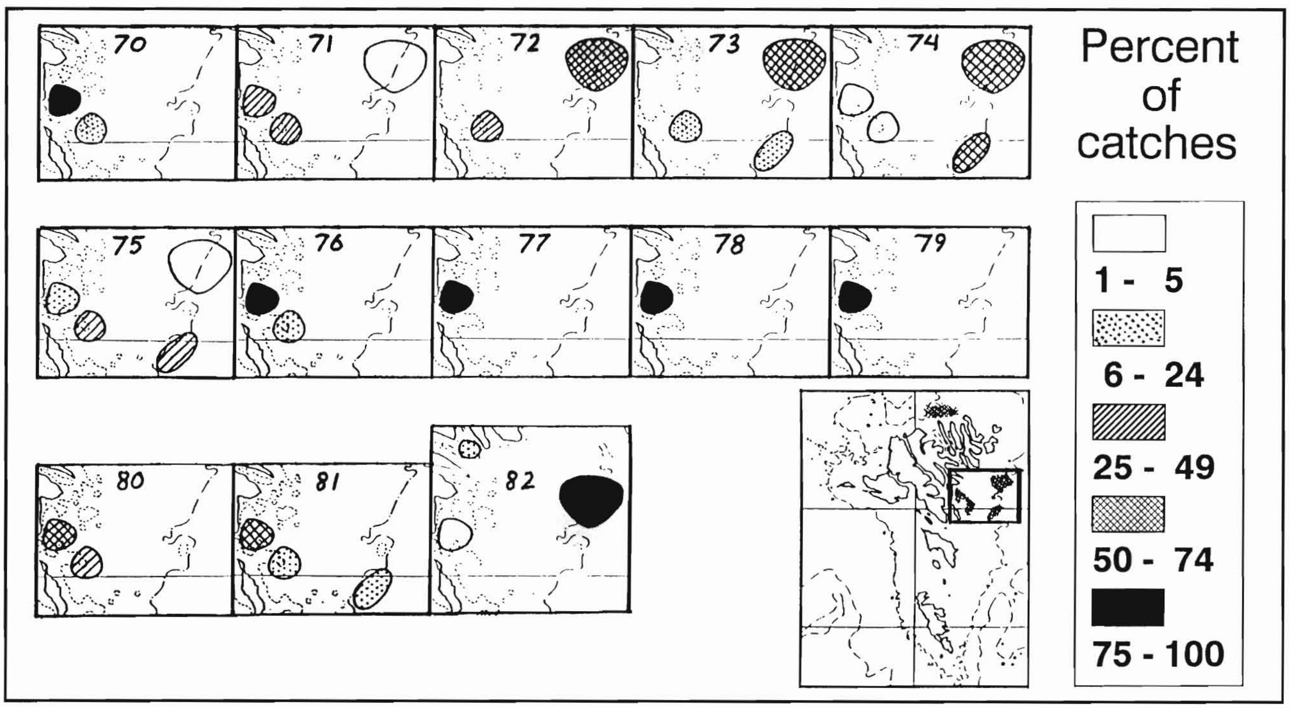

Figure 6
Development in distribution of catches of the queen scallop, Faroe Islands, in the period 1970–82. The number on the top of each frame refers to the season, i.e. 70 = 1970/71. From Nicolajsen (1984).

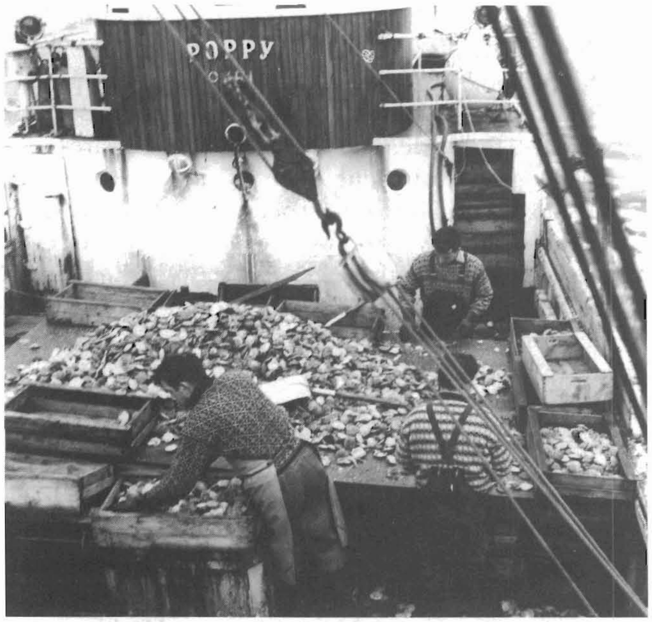

Figure 7
Part of the catch of queen scallops on deck of a dredging vessel.

Figure 8
A Faroe Islands 12-foot dredge for the queen scallop.

The period 1978–87 started with a high CPUE of about 64 kg/foot/hour mostly due to a shift of gear from a light 12-foot Scottish type dredge to a heavier Faroes-type 12-foot dredge (Fig. 8). The number of vessels were 2–5, though two of them caught more than 95% of the catches, as they were the most efficient vessels.

In 1980 a larger vessel (180 BRT) replaced an older vessel (80 BRT), and from 1982 it towed two dredges at a time, thereby increasing its effort and catches considerably (Fig. 9). But the two dredges were not used fully as the hauling operation now took longer. This meant a drop in the calculated CPUE which did not take account of this fact.

In more recent years, 1988–91, only one ship has been fishing the traditional beds, and CPUE and total catches have continued to rise. This has been due to the increase in towing speed and eagerness to exploit more intensely, prompted by the prospect of harsh competition from a large scallop factory trawler. This new factory trawler was one of two originally built for Faroes shipping companies for the Iceland scallop fishery in the Barents Sea in 1987 (Fig. 10, 11). As the fishery for the Iceland scallop, *Chlamys islandica*, collapsed in 1988–89, one of these trawlers applied for fishing permission at the Islands, and this was granted provided that it was outside the traditional eastern scallop beds. It had been known from the ongoing fishery and from fisheries investigations that some beds were outside the traditional fishing grounds, but now a larger

Figure 9
A 180-BRT vessel, *Norðheim*, which towed two dredges for the queen scallop.

Figure 10
The factory scallop dredger, *Fame* (in the middle of the picture).

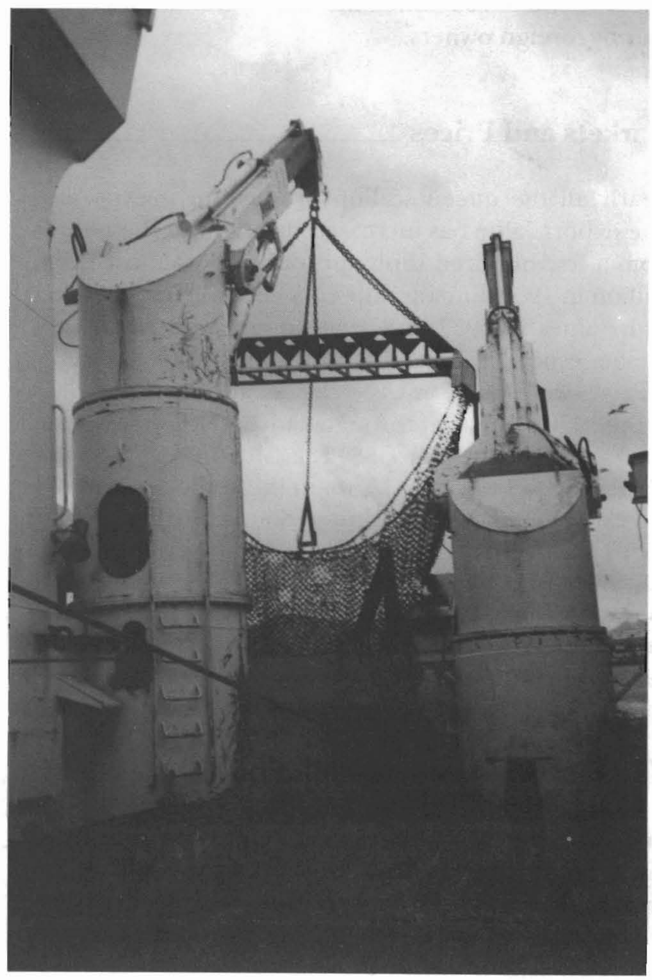

Figure 11
View of scallop factory trawler, *Fame*, showing part of raised dredge.

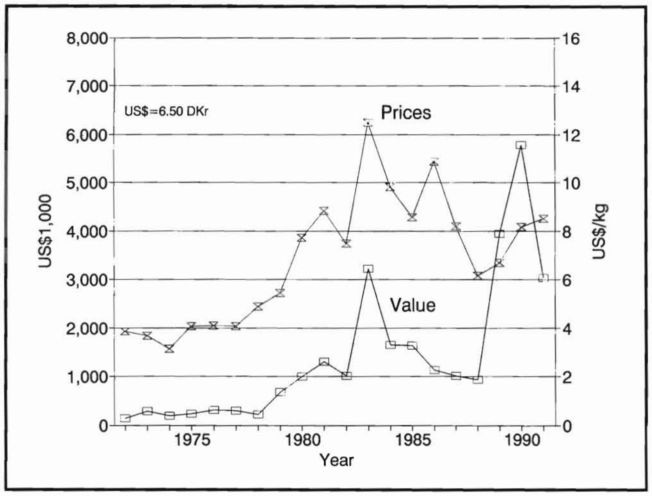

Figure 12
Export value and prices of the queen scallop, 1972–91.

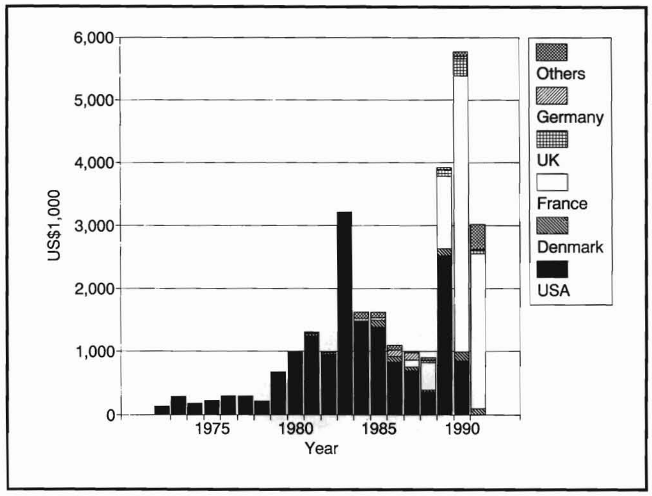

Figure 13
Export value and markets of the queen scallop, 1972–91.

ship was willing to search more effectively. It soon discovered a comparatively large area of about 100 km^2 north of the Islands with high concentrations of scallops. This area was fished for several months each year until the end of 1990 when the factory trawler was taken over by foreign owners.

Markets and Prices

Nearly all the queen scallop production is exported. The export value has increased throughout the period from a few hundred thousand dollars to almost US$6 million in 1990, but was only US$3 million in 1991. The high values in 1989 and 1990 were due to increased catches especially from the northern area.

Prices were stable at US$4/kg (of adductor muscles) in the 1970's but went through a turbulent phase in the 1980's, peaking at over US$12/kg in 1983. In 1988 the price dropped to US$6/kg when the scallops were sold to France instead of the United States. During the last two seasons, prices have been around US$8/kg (Fig. 12). In most of the period, almost all production went to the U.S. market and the remainder to Europe. But since 1988 more and more has been sold to France. In 1991 none went to the United States (Fig. 13).

The Environment and Pollution

The environmental question has never been an issue in the Faroes queen scallop fishery, as the beds are in areas with strong currents and there is practically no industrial waste apart from inshore eutrophication created by the fishing industry and farming of Atlantic salmon, *Salmo salar*, and rainbow trout, *Oncorhynchus mykiss*. Being reared in areas exposed to organic waste, blue mussels have occasional been affected by PSP, and harvesting has been prohibited for the relevant periods.

The Future

Since the factory trawler stopped fishing in December 1990, about 10 vessels have applied for fishing rights in the northern area. Due to protests from longline fishermen, however, the politicians have bowed to their demands and stopped any further exploitation of this area. In the midst of rising unemployment this hardly seems logical, but the traditional hook-and-line lobby is much stronger than the more recent dredge lobby. As fishing on the eastern area has reached its limit, it might be wiser to spread the current capacity over the two areas instead of allowing new ships into this fishery.

There have been talks of rearing or ocean ranching the great scallop, *Pecten maximus*, which exists sparsely on the Faroe Plateau. Also, resettling of young queen scallops from deeper but less productive waters to shallower and more productive areas has been considered.

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1984. Jomfruøsters (*Chlamys opercularis*) i færøesk farvand, populationsdynamik og fiskeri. [The queen scallop (*Chlamys opercularis*) in Faroese waters, population dynamics and fishery]. Univ. Roskilde, Denmark, Thesis, 83 p. In Dan.

The Molluscan Fisheries of Germany*

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ABSTRACT

The German molluscan fishery has always concentrated on the North Sea. Mollusks occur in the Baltic Sea, but are not as marketable. In prehistory and the Middle Ages, coastal inhabitants gathered mussels, *Mytilus edulis*, cockles, *Cerastoderma edule*, and flat oysters, *Ostrea edulis*, for food and also used mussels as agricultural fertilizer. An organized oyster fishery developed in the 16th century and had considerable economic importance for 300 years. Oysters were dredged with sailing vessels near the coast, as well as far offshore. Catches peaked in the second half of the 19th century at 3–5 million oysters per year. They declined dramatically in the following decades due to permanent recruitment failures, and the flat oyster finally disappeared from the German coast in the 1950's. An organized fishery for freshwater pearl mussels, *Margaritifera margaritifera*, also developed at the end of the Middle Ages, but mismanagement and environmental degradation since the late 19th century have brought this species to the brink of extinction as well. Other mollusks harvested on a smaller scale in the past have been softshell clams, *Mya arenaria*, and whelks, *Buccinum undatum*. The modern mussel fishery for human food began in 1929 with the introduction of novel dredging methods. Annual catches were in the order of a few thousand tons during the first half of this century and have attained 20,000–60,000 tons since the early 1980's; concomitantly, prices have increased five-fold in recent decades. The fishery is now based on 14 highly specialized vessels harvesting from 3,800 ha (9,500 acres) of culture plots which are seeded with mussels from natural beds. Pacific oysters, *Crassostrea gigas*, were first introduced in the 1970's, and a natural population has recently begun to establish itself. They are cultured by one company which imports half-grown seed from the British Isles. A nearshore hydraulic dredge fishery for cockles began in 1973, but was banned for political reasons in 1992. It was replaced by a new offshore fishery for hard clams, *Spisula solida*, which ended when the clam stock suffered total mortality in the 1995–96 ice winter. The molluscan fisheries and aquaculture sector (production and processing) in 1995 employed almost 100 people year-round and another 50–100 seasonally. The annual product is about US$35 million.

Introduction

Germany has about 2,000 km of coast (about half on the North Sea and half on the Baltic); the German molluscan fishery, however, has always been concentrated in the North Sea sector (Fig. 1). Shellfish consumption was of only local importance until the 20th century. Modern processing and marketing now make fish and shellfish available throughout the country, and per capita seafood consumption is slowly increasing. It has

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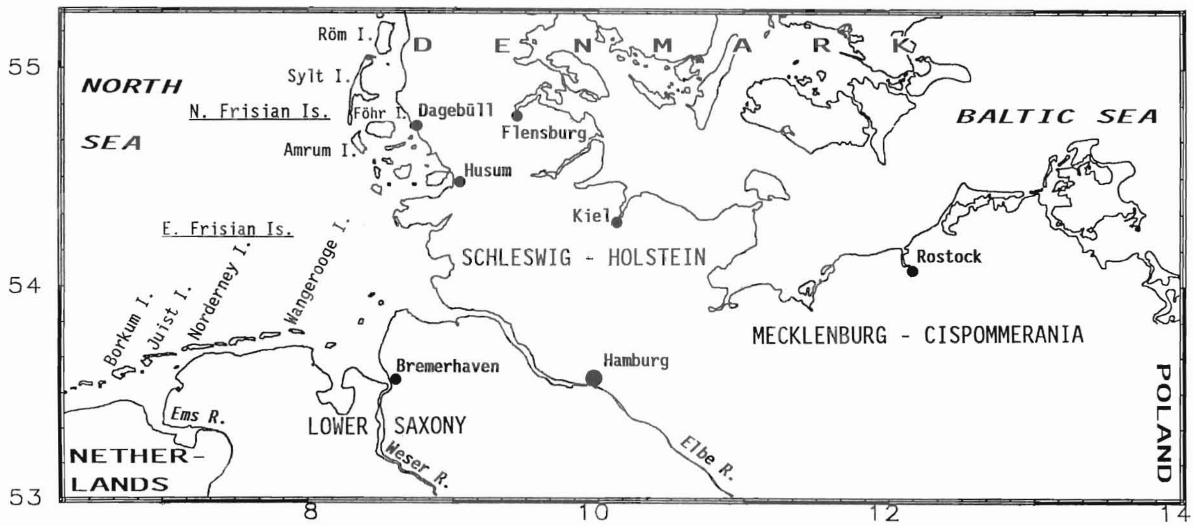

Figure 1
The German coast: Molluscan fisheries have always been based on the North Sea sector.

attained 14 kg per year (twice as much as in the U.S., but only one-tenth that of Japan), 20% of which is shellfish.

The Wadden Sea

The German North Sea coast is characterized by 5,000 km^2 of tidal flats and channels, which are largely protected by island chains and interrupted by the Weser and Elbe estuaries. This shallow coastal area (Fig. 2), termed the Wadden Sea, extends up to 30 km off the mainland shore. There are two daily tides, with average amplitudes between 1.7 m on the open coast and 3.5 m in inlets; current speeds may surpass 3 m/second in the tidal channels, and 1 m/second on the flats. Storms are frequent. The turbidity of the water is very high, and particulate inorganic matter levels may attain several grams per liter. The grain size of the bottom sediments varies from 2 mm (coarse sand) to 0.002 mm (clay), depending on local current and wave action.

The Wadden Sea is subject to extreme environmental fluctuations. The average salinity is around 30‰, but the effects of evaporation and precipitation are often very important; annual fluctuations from 20° to 34‰ are common, and short-term variability is from 0 to 40‰. Water temperatures are around the freezing point in winter and may be more than 20°C in the summer; on the tidal flats, the daily temperature variation at the surface of the substrate may be more than 30°C, and more than 60°C in the course of the year. Periodic winter ice conditions may almost wipe out the macrofauna on the tidal flats, but the populations generally recover in the following spring and summer (Wolff, 1983; Reise, 1985; Beukema, 1989).

The vegetation consists mainly of *Spartina, Zostera, Enteromorpha, Ulva,* and *Fucus* species. The benthic macrofauna consists of relatively few particularly adapted species, but these may be present in enormous numbers. Bivalves account for more than two-thirds of the Wadden Sea biomass. According to Wolff (1983), the most important are blue mussels, *Mytilus edulis* (23% of the biomass in ash-free dry weight); softshell clams, *Mya arenaria* (17%); cockles, *Cerastoderma edule* (16%); and *Macoma balthica* (8%). These biomass values are subject to great fluctuations from one year to another (Asmus, 1987; Beukema, 1989; Obert and Michaelis, 1991).

Except in the case of blue mussels, there are no recent large-scale surveys of the German bivalve stocks; we estimate that the predominant species at present are the Atlantic jackknife clam, *Ensis directus* (introduced from America in the late 1970's; Essink, 1986); the hard clam, *Spisula solida* (in deeper waters seaward of the Wadden Sea); *Mytilus edulis;* and *Cerastoderma edule,* in that order. The larvae of *Ensis* are by far the most abundant in the plankton (Pulfrich, 1995). All of these bivalves are burrowers, except for blue mussels, which form dense natural beds in which the individuals attach to each other by their byssus threads; although the mussels make up 20–70% of the biomass in many areas, they occupy only 1% of the space. The once very com-

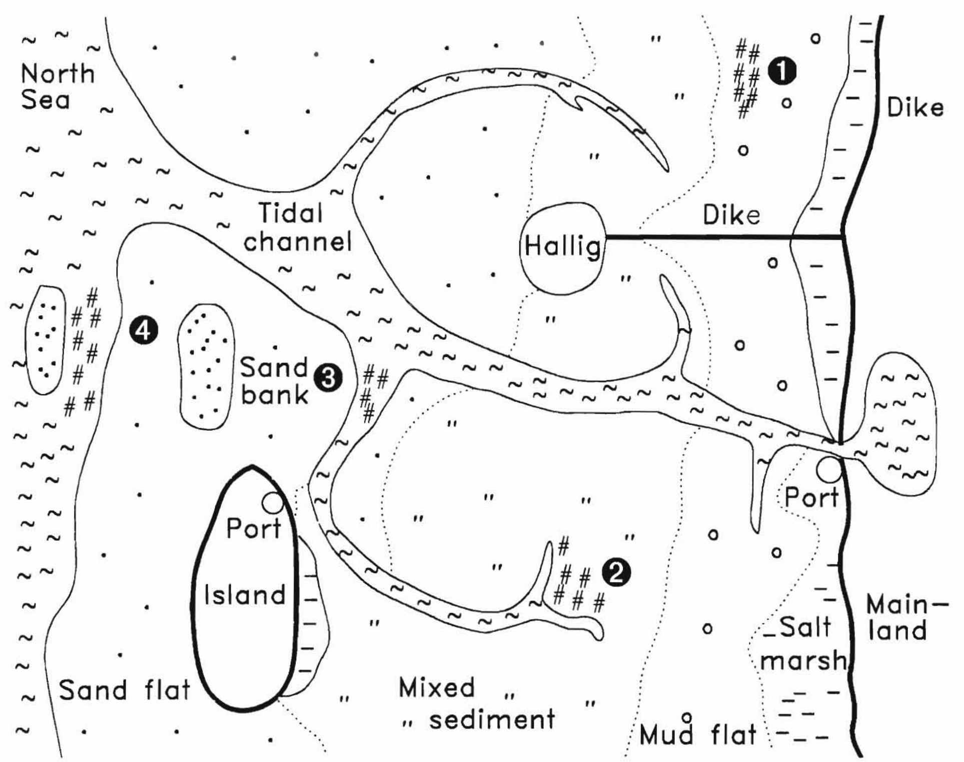

Figure 2
Diagram of the Wadden Sea coastal area: # are mussel aggregations (1 = wild bed, high intertidal; 2 = wild bed, low intertidal; 3 = culture plot; 4 = wild bed, subtidal). A "hallig" is a small island not protected by a dike.

mon flat oyster, *Ostrea edulis*, vanished from the German coast in the 1950's. The most important gastropods are whelks, *Buccinum undatum*; periwinkles, *Littorina* spp.; and *Hydrobia* spp.

The adult mollusks are preyed upon by large numbers of birds, mainly eider ducks, *Somateria mollissima*; seagulls, *Larus* spp.; and oystercatchers, *Haematopus ostralegus*. Mussels are also consumed by starfish, *Asterias rubens*. Bivalve spat and juveniles are taken by shore crabs, *Carcinus maenas*; brown shrimps, *Crangon* spp.; and by fishes (mainly plaice, *Pleuronectes platessa*) (Wolff, 1983; Reise, 1985, 1992; Michaelis, 1992; Nehls and Ruth, 1994a, b).

The Western Baltic Sea

In the Baltic Sea, tides and currents are negligible, and the water attains depths of more than 10 m very close to shore. Bottom sediments are mainly fine sand and silt. Environmental conditions are more stable than in the Wadden Sea, except for marked seasonal fluctuations in salinity, with surface values from 15 to 23‰ at Flensburg Fjord, and 8–17‰ off the coast of Mecklenburg; bottom water salinities are about 10‰ higher. Annual temperature fluctuations are between 0°C and 20°C (Siedler and Hatje, 1974). Oxygen deficiency in the bottom water has become an increasing problem in recent years (Weigelt and Rumohr, 1986).

The brackish character of the Baltic Sea reduces the number of species, and there is also a reduction in benthic biomass with decreasing salinity. Bivalves generally account for 90% or more of the benthic biomass off the German coast. The main bivalve is the quahog, *Arctica islandica*, with local densities of 100–500 g/m^2 fresh weight; other important bivalves are *Abra alba*, *Macoma balthica*, *Astarte borealis*, *Cerastoderma* spp., and *M. edulis*. The low salinities in the inner Baltic cause stunted growth, sterility, and brittle shells in many species; on the other hand, many shallow-water species are also found at greater depths where the salinity is higher (e.g. mussels at 100 m). The main predators of bivalves are fishes, such as cod, *Gadus morrhua*, and flatfishes (Arntz, 1978; Theede, 1981).

History of the German Molluscan Fisheries

Large piles of molluscan shells have been found associated with Stone and Iron Age and Viking settlements. The most common shells found in Iron Age kitchen middens are those of blue mussels, *Mytilus edulis*, and cockles, *Cerastoderma edule*; other bivalves (mostly flat oysters, *Ostrea edulis*), and gastropods (mostly periwinkles, *Littorina littorea*) were consumed less often (Harck, 1973). Canute the Great, King of England, Denmark and Norway, reportedly had oysters brought from England to the West Coast of Schleswig in the first half of the 11th century A.D.; artificial oyster beds are also said to have been established during his reign (Müller, 1938; Arnold, 1939). Since the 13th century, the North Frisians brought their produce, fish, and oysters by boat to the market in Hamburg (Hansen, 1877).

Reliable descriptions of the prehistoric and medieval fisheries, however, are lacking. Coastal inhabitants gathered mussels and oysters for private consumption, and mussels and brown algae were also used as agricultural fertilizer. The mollusks were presumably collected by hand, rake, or fork on the extensive tidal flats at low tide and transported to the shore, either on small boats or with mud sledges drawn across the flats. There were attempts to reserve oyster consumption for noblemen, but poaching was common. There are no indications of trade or transport inland, and molluscan consumption was probably limited to the coastal zone.

Traditional Flat Oyster Fishery

A systematically organized German oyster fishery first developed off the islands of Sylt and Föhr on the west coast of Schleswig-Holstein in the 16th century. The region was still under Danish overlordship at the time, and the first historical record is a decree by the Danish King Frederick II, dated 4 February 1587, in which the harvesting of oysters without permission is placed under punishment in order to protect the stocks from overfishing. The oyster fishery, reviewed by Schnakenbeck (1928, 1953), Müller (1938), and Neudecker (1990), became an important economic activity in the 17th century, even leading to military skirmishes between German and Danish, and between German and Dutch fishermen, as well as among German fishermen from different islands. Swedish merchant ships repeatedly robbed North Frisian fishermen of their catch in the Elbe estuary, as they were sailing to market in Hamburg, temporarily bringing the oyster fishery to a halt in the 17th century (Hansen, 1877). In the 18th century the stock off the shore of Wangerooge in Lower Saxony was protected against poachers by the installation on the dike of four cannon and a gallows (Linke and Rüthning, 1937).

The oysters were fished with single-masted sailing vessels and iron dredges (Fig. 3, 4); this method had probably been used since the 13th century, but it was not until the 17th century that priests began to teach mathematics and navigation to the fishermen. Considering the frequently gusty winds and choppy seas, as well as shifting shoals and treacherous tidal currents in the Wadden Sea, the oyster fishery must have demanded extraordinary skill. According to parish chronicles, it also claimed many a fisherman's life. Conditions on the coast were generally harsh, and storm floods often killed thousands of people, sometimes depopulating entire islands.

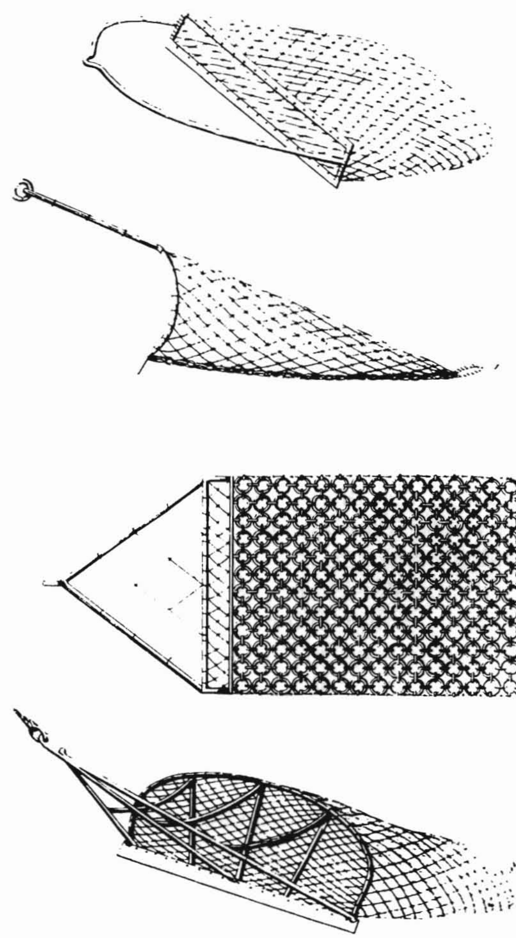

Figure 3
Early 19th century iron dredges used in the oyster fishery (after Kroyer, 1837; from Neudecker, 1990).

The Schleswig-Holstein oyster fishery was economically more important than that off Lower Saxony, and has consequently been described in better detail. The King of Denmark began leasing the beds of Schleswig-Holstein in 1627; the entire lease was held by one person (generally a wealthy merchant or a company) for several years. More than 100 fishermen from the islands of Rømø, Sylt, and Amrum, working on about 30 boats, were employed by the leaseholders, but due to natural constraints (such as tides and weather conditions), the oyster fishery probably offered employment for no more than 40 days per year; at other times, the men would engage in other seagoing activities (ranging, for instance, from acts of piracy to whaling in the Arctic Ocean), or they might tend to their land plots.

Crisis and Management of the Fishery—The price for the lease of the oyster beds in Schleswig-Holstein increased continuously from 60 Reichsthaler (Rtr.) in 1627 to 6,000 Rtr. in 1728 (at the time, 1 Rtr. probably corresponded to the weekly income of a worker, so that the 18th century price of the lease would be more than US$3 million in present terms); in addition, the leaseholders had to deliver several tons of oysters free of charge to the royal court in Copenhagen and to local noblemen every year. This created a financial pressure on the leaseholders that led to overexploitation.

Destruction of oyster beds by overfishing and ice winters was a constant problem since the end of the 17th century, and systematic management began in 1703 with the closure of the beds for 3 years. From 1709 on, overfishing, fishing during the reproductive season (May–August), and the sale of undersized oysters (less than 7 cm in diameter) were forbidden. Regular inspections of the oyster beds by government officials became the rule, and in the 18th century the position of royal superintendent of the oyster fishery became a highly respected and lucrative office (Müller, 1938).

As in Roman times, the oysters were eaten raw on the half-shell; they were reputed to have medicinal properties, but the ill effects of consuming raw oysters which had been stored out of water for too long were also well known (Anonymous, 1731). Most of the catch was marketed in Hamburg, and oysters were sometimes shipped

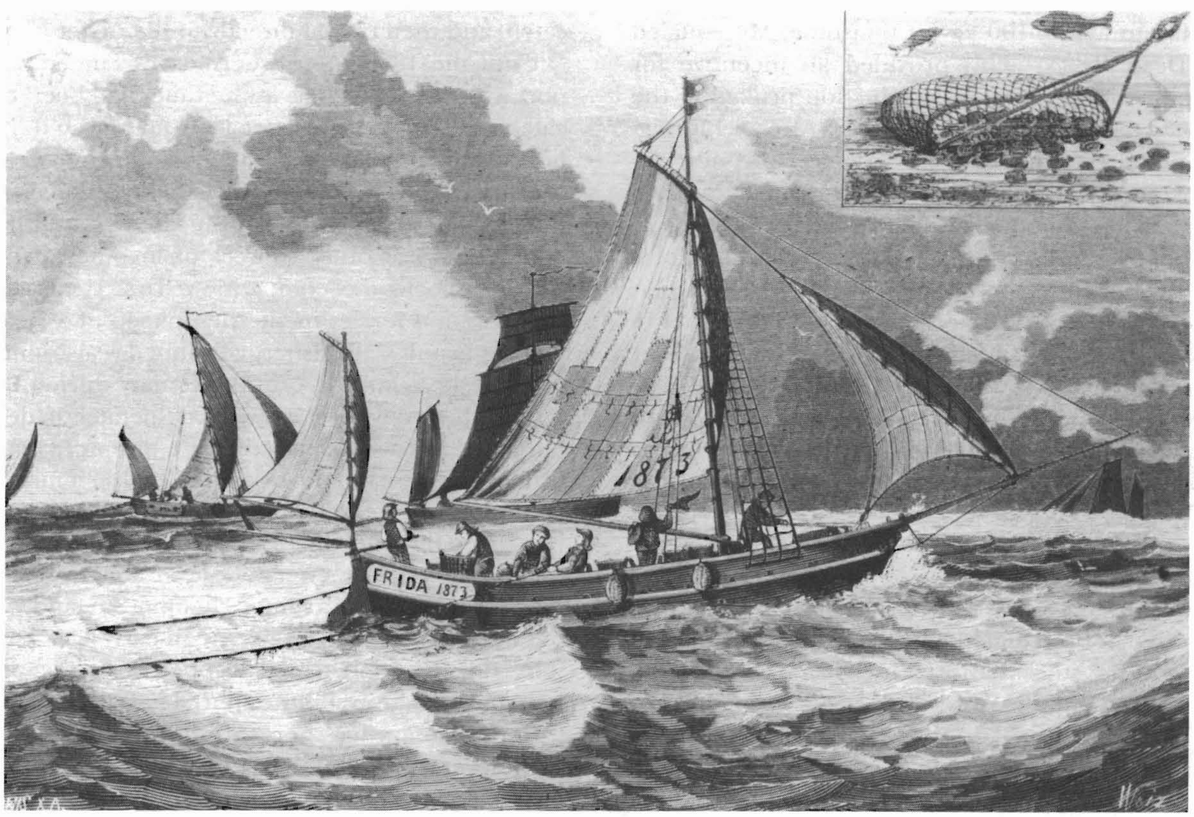

Figure 4
19th century oyster cutter from Sylt Island. The boat is towing two dredges; the inset (upper right) shows a typical dredge (Engraving by R. Weix; copyright by Altonaer Museum, Hamburg).

as far as Hungary and Russia. The increasing market demand was met by the import of cheaper oysters from England and the Netherlands; when landings from the Wadden Sea were high, the market price in Hamburg would drop by 75% in the course of one day, and the leaseholders often lost money on the venture.

After a severe ice winter nearly wiped out the stock in 1829–30, the fishery took 25 years to recover. Fishermen from Hamburg and the Netherlands attempted to exploit deep-water stocks off the coast of Schleswig-Holstein, but the activity proved too difficult at the time, and the oysters were too poor in quality, to be economically feasible. There were attempts to introduce oysters to Mecklenburg and Pomerania in the Baltic in 1753, 1830, and 1843, but the oysters quickly died in the low salinity (Möbius, 1887). The difficulties of the Schleswig-Holstein fishery also led to increased exploitation of the oyster stocks in Lower Saxony, and the fishery off Juist and Borkum yielded almost 200,000 oysters yearly from 1841 to 1846; it collapsed in the 1850's because of overfishing and silt deposition on the oyster beds (Linke and Rüthning, 1937).

From 1859 on, 40,000 oysters were relayed every year to repopulate the beds in Schleswig-Holstein. The market price in Hamburg tripled between 1860 and 1875 from M35 to M105/100 kg (at that time, M4 equaled US$1; Dean, 1893). This provided an incentive for overexploitation again, and production peaked in the 1860's at 4–5 million oysters per year. After Schleswig-Holstein came under Prussian control, the new authorities conducted a survey of the fishery in 1868 (Müller, 1938). The oyster fishery employed 60 fishermen from Sylt and Amrum, working on 23 boats, plus several artisans and the crew of a transport steamer. Harvested oysters were taken directly to the market in Hamburg or stocked in the port of Husum in four saltwater ponds with a storage capacity of 150,000–400,000 oysters. In 1878–80, 52 oyster beds were known (more than twice as many as in 1724), varying from 1 to 242 ha (2.5–598 acres) in size, and their total surface was 1,785 ha (4,410 acres).

Decline of the Wadden Sea Oyster Stock and Fishery on Deep-water Stocks—In the 1870's the annual catch from the Wadden Sea fluctuated between 1.2 and 3.2 million oysters, but the stocks suffered increasing recruitment problems, forcing a closure of the beds from 1882 to 1891. The stock, however, did not recover, and landings in Schleswig-Holstein decreased from 1 million oysters per year in the early 1890's to about 300,000 in 1910 (Müller, 1938), with consequent price increases. The fishery in Lower Saxony no longer existed and a deep-water stock off Heligoland Island collapsed in 1882.

The market supply was maintained by a wintertime fishery on the oyster stocks of the outer German Bight, located 100–150 n.mi. offshore in 40 m of water. This fishery lasted from 1885 until 1914 and was based on the port of Finkenwerder near Hamburg (Schnakenbeck, 1928; Broelmann and Weski, 1992). The initial landings were 3 or 4 million oysters per year, and roughly 1 million per year from the mid–1890's until the beginning of World War I (estimated after Ehrenbaum, 1892, and Anonymous, 1913). The overall annual catch, however, must have been much higher (possibly close to 10 million oysters), because the same stocks were sometimes exploited by other German, Dutch and English fishermen, including motorized vessels catching demersal fishes (with oysters as bycatch).

The boats from Finkenwerder were two-masted ketch-rigged smacks and cutters (Fig. 5) 20 m in length, with crews of three. The oysters were caught with 26-ft (8 m) beam trawls (and with British-type otter trawls after 1903) whose netting was reinforced with coconut fiber. The fishing season was from November to March; a single trip generally lasted 2 weeks, but under adverse conditions the men were sometimes forced to stay at sea as long as 4 weeks. The oysters were landed at Cuxhaven, where they sold for M4 (US$1) per hundred. When winds were foul, however, the men might sail to the Netherlands, Denmark or England to sell the catch, and then return directly to the oyster grounds.

Until the 1880's the fishermen of Finkenwerder, a port with 100–200 boats at the time, had been content catching flatfish near the coast from March to November, laying up the boats in winter. At the end of the 19th century, however, the increasing competition from capitalist fishing steamers, the ensuing decline in fish stocks, and the loss of other sources of income in the Elbe estuary due to the competition from steam-powered tugboats and ferries made the upkeep of a smack unprofitable unless the fishery continued year-round. Most of the fishermen fished in the estuary during the winter, but the young captains, often desperately in debt after purchasing boats, were forced into the profitable oyster fishery, regardless of the risk and hardship it meant.

Because the gear had to be hauled aboard every few hours and the catch was immediately cleaned on board, the men were always wet and never able to sleep more than two hours at a time; rheumatism and arthritis often forced them to give up at an early age. The boats were not designed to sail in open seas, nor did they have the maneuverability required in the German Bight, with permanent lee shores to the south and east. The men never survived if their boats sank; the annual mortality rate of fishermen was 5%, and there were hardly any pensions for the widows and orphans (Broelmann and Weski, 1992).

The deep-water fishery had to be discontinued during World War I; it did not resume after the war because the oysters rapidly disappeared.

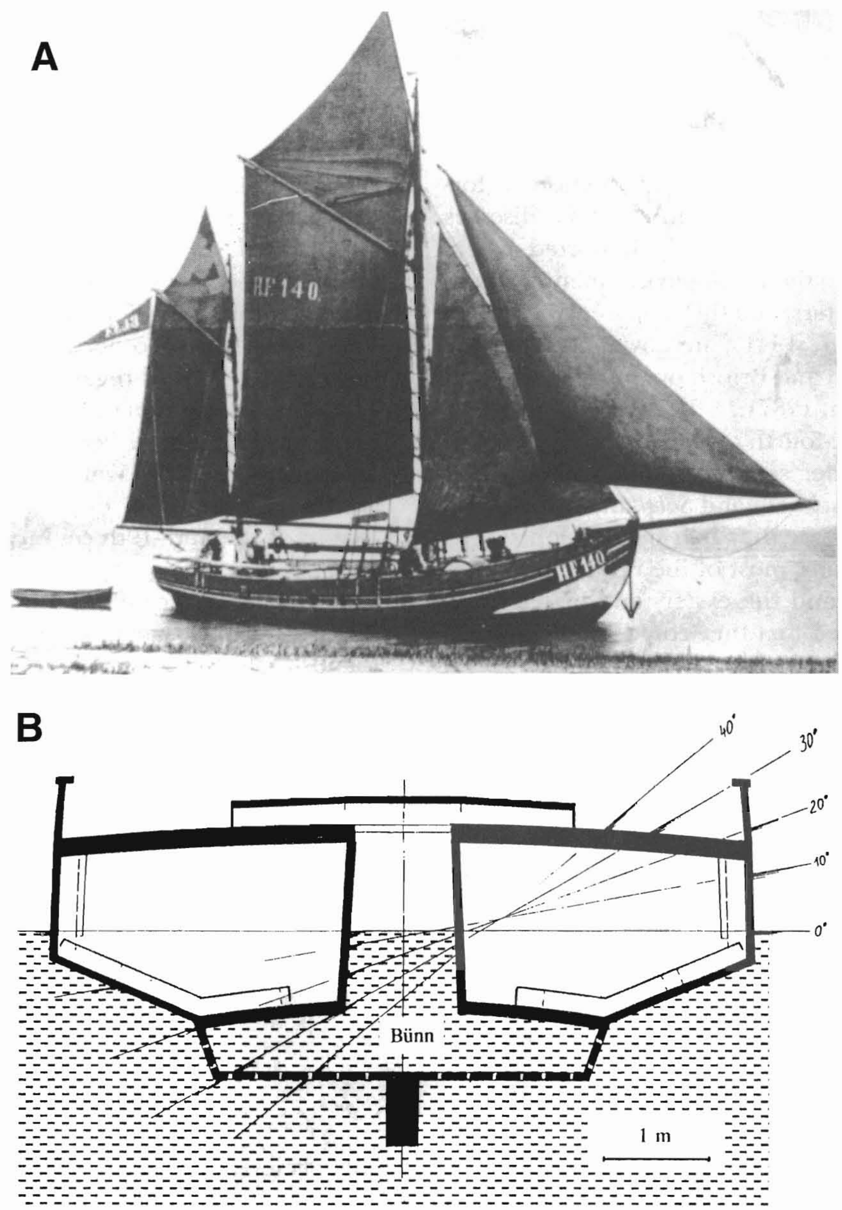

Figure 5
A (top)=Fishing smack from Finkenwerder, Hamburg (copyright by Museum of Transportation and Technology, Berlin). For centuries this type of boat was used in shallow-water finfisheries. It had a flooded hold (the "Bünn") under the water line (B, after J. Broelmann, modified), enabling the fishermen to bring the catch (mostly flatfish) alive into the port. In the oyster fishery on the open sea, however, the Bünn might cause the boat to capsize in heavy weather; if it listed by more than 20°, air could enter into the hold through the perforations below and leave the boat without ballast (Reproductions from Broelmann and Weski, 1992).

Disappearance of the Flat Oyster—In the late 19th and early 20th century there were repeated attempts at oyster culture, spat collection, and artificial breeding by French and Dutch methods (initiated by Möbius, 1877; see also Dean, 1893), as well as various management efforts (Hagmeier, 1916; Hagmeier and Kändler, 1927), but they all failed. From 1894 to the 1930's, hundreds of thousands and sometimes millions of spat and half-grown oysters from the Netherlands, France, and Norway were relayed on the Schleswig-Holstein beds almost every year. This allowed the shallow-water fishery to resume, and a fishing steamer (Fig. 6) was put into service in 1911. The continuous introduction of foreign oysters, however, also introduced various diseases and fouling organisms. Moreover, the imported oysters were not as resistant to the harsh environmental conditions as the native oysters, and they apparently failed to reproduce (Hagmeier, 1941); in Lower Saxony, the introduction of Dutch and British oysters met with outright failure (Sarrazin, 1987).

By 1925, about one-fourth of the coastal oyster beds had disappeared under sand banks, and almost half had given way to mussel beds and *Sabellaria* (tube-dwelling polychaete) reefs, or they had been colonized by various other organisms; most of the remaining oyster beds were depleted, and the oysters and oyster shells were so strongly fouled that they could hardly provide settlement surfaces for oyster larvae (Hagmeier and Kändler, 1927). The fishery continued on Sylt and Föhr with Dutch seed into the 1930's, but annual production ultimately declined to a few thousand oysters. By then, Hagmeier (1941) had already concluded that the oysters had been outcompeted by mussels (and also by slipper shells, *Crepidula fornicata*), and he predicted that a return to the traditional fishery would not be possible. The last living oysters were sighted in the early 1950's.

The deep-water oyster stocks were almost certainly destroyed by the heavy gear of motorized fish trawlers (Anonymous, 1913), but the reasons for the prolonged recruitment failures which resulted in the extinction of the Wadden Sea stocks are unknown. Habitat changes, such as the secular rise of the sea level and the increase in tidal amplitude (Führböter, 1989) may have favored some species over others, but there have also been various speculations regarding anthropogenic effects. The same phenomena as described by Hagmeier and Kändler (1927) have been made responsible for the disappearance of the Wangerooge oyster stock in 1806 and for the downfall of the oyster fishery of Lower Saxony in the mid–19th century (Linke and Rüthning, 1937).

Since the 17th century, the continuous building of dikes for land reclamation and for connecting various islands to the mainland caused changes in the Wadden Sea hydrography; the topography of the bottom always needs a few decades to adjust (Gerritsen, 1992; Höck and Runte, 1992), and there may have been a perpetual mismatch between hydrographic conditions and the

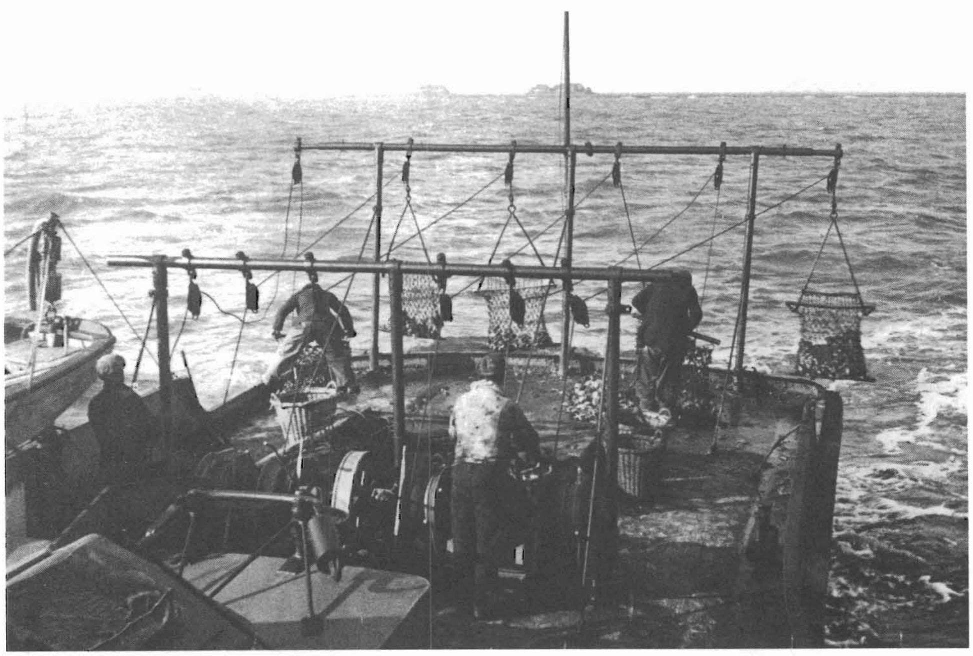

Figure 6
Oyster steamer "Gelbstern" from List (Sylt) in 1927. This vessel was about 25 m long and was propelled by two paddlewheels located amidships on either side of the hull. It could tow six dredges simultaneously (Photograph by R. Kändler; courtesy of Heye Rumohr).

substrate for larval settlement. This may also explain why existing oyster beds constantly suffered from siltation or disappeared under sandbanks. In the 1920's, finally, the recruitment problems may have been compounded by the destruction of the offshore stocks, which were probably ten times greater than the Wadden Sea stock and which may have been an important source of larvae.

Evolution of the Fishery for Blue Mussels

The German mussel fishery is a relatively recent activity. Before the 19th century, mussels were mentioned in documents only in relation to the necessity for their removal from oyster beds. The first written records on mussel consumption are from the Napoleonic Wars; in 1812, the East Frisian Islands were occupied by French troops, and in the following severe winter the mussels saved the soldiers from starving. As is still the case today, the mussels were eaten after being boiled in water. Nineteenth century documents show that the coastal population regularly consumed mussels in times of famine, and in the Western Baltic mussels were cultured on "stakes" (trees with the smallest branches removed). In Kiel Fjord during the second half of the 19th century about 1,000 such stakes were driven into the bottom in 4–5 m depths every year. The mussels were harvested after 2–5 years for an annual yield of about 80 metric tons (t) (over 3 million mussels; Meyer and Möbius, 1865). Mussel cultivation in the Baltic was given up during the 20th century for unknown reasons.

Heins (1868) urged North Sea fishermen to attempt the cultivation as well, but mussels were regarded as a poor man's food, and on the North Sea coast they were mainly fished for use as fertilizer until the beginning of the 20th century. The mussels were caught at low tide with rakes and forks and brought in small boats to sailing cutters waiting in deeper water, from which the catch was landed in the harbors at high tide. The fishing season was from September to April, avoiding warm weather. Landings have been recorded by fisheries authorities since 1887 in Lower Saxony and since 1914 in Schleswig-Holstein[1].

The first motor-powered vessel was put into use in 1909, but until 1914 only a few hundred tons were landed annually, and only a dozen fishermen and vessels participated in the fishery. Increased demand during World War I resulted in a record catch of almost 10,000 t in 1916–17, and almost all German fishing vessels with a sufficiently shallow draft were involved. The strong fishing pressure and the effects of ice winters led to a collapse of the fishery in Schleswig-Holstein in 1919. In Lower Saxony, annual landings were about 1,100 t throughout the 1920's (Schnakenbeck, 1928, 1953; Nolte, 1976; Sarrazin, 1987; Kleinsteuber et al., 1988).

Development of a Mixed Fishery in Lower Saxony— The mussel fishery in Lower Saxony recovered with the beginning of mechanization in 1929. The rake-and-fork method was abandoned in favor of dredges developed by Dutch fishermen, leading to higher daily catches and to the exploitation of subtidal stocks. Annual landings more than doubled, and a marketing company was formed in 1933 to stabilize prices. The use of mussels as animal feed was banned in 1934. By 1937, the fishery employed more than 60 fishermen on 26 vessels; these were motor-powered (15–60 hp) and 10–15 m long (Fig. 7). Mussels were loaded on deck. Extensive cultivation on reserved plots around the low-water line was reintroduced (first attempts in the 1920's had failed), and more than 31 licensed plots existed by 1939. After the outbreak of World War II, catches peaked at more than 5,000 t in 1939–40, but the fishery subsequently collapsed due to overfishing and ice winters.

In the post-war period, mussel catches remained low, again owing to winter ice mortalities, and to the infestation of the mussels with *Mytilicola intestinalis*. These parasitic copepods initially caused high mortalities or rendered the mussels unmarketable because of the reduction in meat content; the mussel populations seem to have adapted in the following 20 years, and *Mytilicola* infestation no longer causes mortality or weight loss (Dethlefsen, 1975; Nolte, 1976). In the 1950's, however, many fishermen had to abandon their culture plots and use their multipurpose boats to catch mainly finfish and shrimp. In 1965, there were 10 fishermen involved in the mussel fishery in Lower Saxony using vessels 15–20 m in length with an average of 80 m^3 hold capacity and 130 hp engines. They managed 25 culture plots with 180 ha (450 acres), but most of them also engaged in other fisheries.

A Specialized Fishery in Schleswig-Holstein—The mussel fishery in Schleswig-Holstein resumed in 1934 with the introduction of the first specialized Dutch-type mussel dredging vessel. These low-draft boats were 15–21 m long and had engines of 75–100 hp; they could simultaneously operate 2 or 4 dredges which were emptied into a hold. Most of the landings were from natural beds; the catch could attain 40 t in one day, and total landings increased to 2,000 t in 1939. More than 9 such boats (some of them confiscated from Dutch owners) were in operation during World War II, leading to a

[1] In Lower Saxony: Staatliches Fischereiamt, 27534 Bremerhaven. In Schleswig-Holstein: Fischereiamt des Landes Schleswig-Holstein, 24148 Kiel. Data on landings and prices are also regularly published as part of the annual reports of the state fisheries agencies in Das Fischerblatt, Schleswig-Holstein Chamber of Agriculture, Kiel.

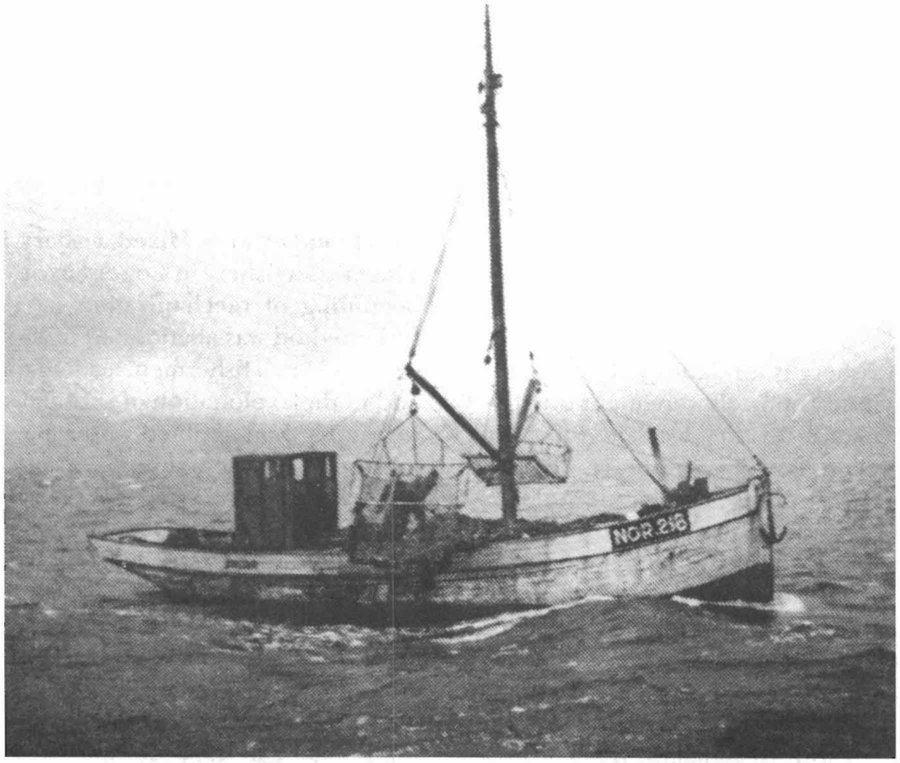

Figure 7
Boat used in the mussel fishery off Lower Saxony around 1930. Two dredges can be seen hanging from the booms. This type of boat could also be used to catch finfish and shrimp (Photograph by Willy Nolte; from Nolte, 1976).

record yield of 15,000 t in 1942–43. The fishery lost most of its Dutch vessels in 1945, but catches remained stable at 2,000–4,000 t in the post-war period; *Mytilicola* infestation of mussels in the Netherlands and Lower Saxony gave the fishermen from Schleswig-Holstein the opportunity to supply the Dutch market. On the other hand, the market demand also motivated shrimpers and Dutch fishermen to exploit the stocks of Schleswig-Holstein, thus increasing the fishing pressure.

In 1950 and 1953, the state legislature passed laws to protect the first post-war culture plots and prevent overfishing of natural mussel beds. The size of the boat hold was limited to 50 m^3, and the number of dredges to two (in addition, engines were limited to 35 hp for mussel boats in the Baltic sector). It was forbidden to transport mussels from other regions into or through the coastal waters of Schleswig-Holstein; culture plots were made subject to licensing, and their borders were defined by decree. These regulations are still in effect, but exemptions concerning the boats' performance are the rule. In 1965 there were 8 companies in Schleswig-Holstein devoted exclusively to mussel fishery, with specialized vessels (about 20 m length, 110 m^3 hold capacity, and 90-hp engines), leasing 35 mostly subtidal culture plots with 380 ha (950 acres).

Other Marine Molluscan Fisheries

Whelks—These gastropods (*Buccinum undatum*) were caught from 1951 to 1974 in Lower Saxony, initially by one boat using special dredges (Fig. 8). The total catch for the 24-year period was 3,000 t (Table 1), mostly originating from the Ems estuary, and all of it was exported to the Netherlands. A consumer demand never developed in Germany. Catches continuously increased at first, inducing other fishermen to join the fishery. Landings peaked at 450 t in 1971, and two specialized vessels (19 m long, 220-hp engines) were built for the whelk fishery in that year. Landings, however, subsequently declined dramatically, and the fishery was given up 3 years later (Nolte, 1976), as the Netherlands began to buy from English producers. According to Lozán (1994), the downfall was due to the fact that 90% of the catch was undersized, making on-board sorting too tedious; on the other hand, the refusal of the German

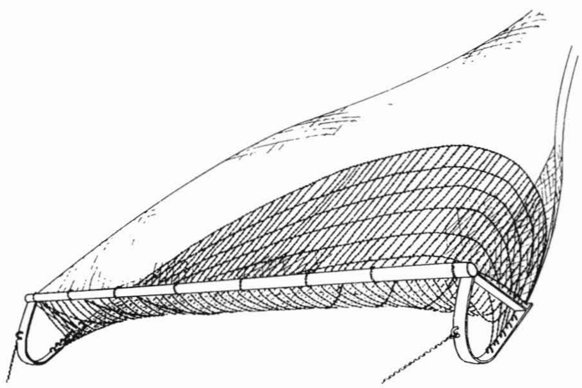

Figure 8
Buccinum dredge. The chain mesh in front of the opening is designed to repel stones, but may also inflict damage on benthic fauna (from von Brandt, 1984).

fishermen to supply the Dutch industry on a regular basis also contributed to the termination of the relationship[2].

Softshell Clams—These clams (*Mya arenaria*), are never found in prehistoric and medieval kitchen middens, nor in recent geological records, and it is presumed that they were introduced accidentally from North America, either around the year 1600 (Hessland, 1946; cited after Berghahn, 1990), or by the Vikings in medieval times (Petersen et al., 1992). They have been fished in the Wadden Sea for use as pig fodder (and for human consumption in times of famine). A regular fishery has never existed, however, and data are scarce, except for the last post-war period.

From 1945 to the early 1950's more than 14,000 t were collected by the coastal population, mainly by digging the clams out of the sand with pitchforks and shovels at low tide (Kühl, 1955). Sometimes, they would be washed out of the sediment by the action of a boat's propeller going full throttle against a dragging anchor in shallow water; the boat would be beached, and the clams loaded aboard at low tide. The most important source of clams was the area north of the Elbe estuary. A clam sausage was produced in the late 1940's, but attempts to initiate a commercial fishery were given up due to the lack of market demand (Neudecker, 1990).

Cockles—According to older fishermen[3], Dutch boats used to land on sand banks off the German coast into the 1960's to collect cockles, *Cerastoderma edule*, by rake; a large-scale fishery, however, did not begin in Germany until 1973. Annual catches fluctuated greatly, because of nearly total ice mortalities in some winters; in Schleswig-Holstein, for instance, landings were nil from 1978 to 1983, and the record catch of 12,500 t (1,600 t cooked meat) in 1983 was all from Lower Saxony. Catches and prices[1] are summarized in Table 2. The landings were almost exclusively exported to the Netherlands for processing and reexport to southern Europe.

There were three companies in Schleswig-Holstein and two in Lower Saxony engaged in the fishery. In each state, one company fished cockles exclusively, whereas the others also held mussel licenses. The fishery was open from July to February, and the cockles were caught by the Dutch method of hydraulic dredging (discussed later). The boats were 30–35 m long, 8 m wide, and had a particularly shallow draft; they were equipped with motors of up to 300 hp and special pumps, as well as with culling and cooking facilities. The catch was usually cooked on board; the empty shells had to be either deposited on land, or ground to a fragment size of less than 6 mm before being thrown overboard at assigned dumping areas. As a minimum size regulation, 600 cockles had to yield at least 1 kg of meat (Hagena, 1992a).

The inception of three national parks covering the entire German Wadden Sea in 1985, 1986, and 1990, drastically reduced the area available to the fishery. In addition, the fishery became increasingly hampered by protests against the hydraulic dredging method, which may remove up to 5 cm off the surface of the sediment. Environmental concern focused on the resulting mortality of benthic organisms, as well as on the dredge marks, which may remain visible on the tidal flats for months. Although scientific studies have demonstrated that the cockle fishery does not seriously harm the environment (de Vlas, 1982, 1987), the fishery was banned for political reasons (1989 in Schleswig-Holstein and 1992 in Lower Saxony; Hagena, 1992b:50).

Table 1
Landings and prices of the whelk fishery (5-year averages, after Hagena, 1992a).

Period	Catch (t/year)	Price (DM/t)
1951–1954	4	430
1955–1959	26	940
1960–1964	89	810
1965–1969	173	980
1970–1974	304	1,220

[2] Wolfgang Hagena, State Fisheries Agency for Lower Saxony and Bremen, 27534 Bremerhaven, Germany. Personal commun., 1992.

[3] Jürgen Petersen, retired fisherman from Wittdün, Amrum Island, and others. Personal commun., 1992.

Table 2

Landings and prices of the German cockle fishery (calculated from official data in the annual reports of the state fisheries agencies; some of the landings were raw cockles, and these have been converted to cooked meat by multiplying by 0.13).

Year	Catch[1] (t/year)	Price (DM/t)
1973	150	1,720
1974	833	1,970
1975	583	1,900
1976	156	1,110
1977	594	1,200
1978	790	2,040
1979	588	1,960
1980	190	1,180
1981	532	1,150
1982	281	970
1983	1,627	1,220
1984	1,319	1,450
1985	459	2,270
1986	194	4,160
1987	757	3,910
1988	191	2,160
1989	431	1,950
1990	744	2,800
1991	528	6,400
1992	14	3,180

[1] Cooked meat.

Extraction of Shell Deposits—Bivalve shells have been burned for the production of lime at least since the 16th century on the North Sea coast (Hansen, 1877). Marine deposits of mollusk shell fragments (so-called "Schill") attain a thickness of several meters in some tidal channels. They were strongly exploited off Lower Saxony by hydraulic dredging with boats in the 1930's and 1940's to meet the high demand resulting from military construction on the East Frisian islands. After World War II, the Schill fishery provided calcium for animal feeds (Michaelis, 1993). It ended in 1967 when the last dredging vessel was shipwrecked[4].

[4] Hermann Michaelis, Coastal Research Station, 26548 Norderney, Germany. Personal commun., 1992.

The Freshwater Pearl Mussel Fishery

Pearl mussels, *Margaritifera margaritifera*, were once extremely abundant throughout Europe, including Germany. Their biology and fishery have been reviewed by Wächtler (1986) and Bischoff et al. (1986). Pearl mussels inhabit cold, fast-flowing oligotrophic waters and are very slow growing; their life span ranges from 60 to >100 years, for a final size of about 15 cm. Although their ability to produce pearls has been known since ancient times, a systematic fishery did not develop in Germany until the 15th century.

Judging by the number of pearls found in 16th and 17th century treasures and relics, the German pearl mussel stocks must have numbered in the tens or even hundreds of millions of mussels. The church and the princes attempted to enforce their exclusive rights with harsh punitive measures (Fig. 9) and strict controls. For the fishermen, as well as for the government inspectors, the pearl fishery was only a part-time occupation, but it was very profitable and well managed in many areas. One rule, for example, was that a given brook or river would only be fished once every 10 years. Mussels with certain shell malformations (so-called "Perlzeichen," which had resulted from earlier damage and indicated that the mussel might carry a pearl) were pried open with a special tool (Fig. 10B), and the pearl was removed without serious injury to the mussel, which was returned to its site.

In some regions, however, it was not known that by the study of Perlzeichen and use of special tools the mussels need not be destroyed to ascertain whether they carried pearls (only one in several hundred actually does), and pearl mussels were broken and thrown on land by the millions. When German unification in 1866 put an end to local and regional management, the exploitation of pearl mussels became a free-for-all and caused a quick downfall of the fishery. Moreover, the species' complex life cycle (its larvae are obligatory parasites on the gills of brown trout, *Salmo trutta*) and its stringent ecological requirements were obscure at the time, and no major attempts were made to save its habitat, which was increasingly suffering the effects of industrial pollution, intensified agriculture, and stream regulation. By the early 20th century, the total number of pearl mussels in Germany had declined to about 5 million, and environmental degradation has since brought them nearly to extinction (Wächtler, 1986; Bischoff et al., 1986).

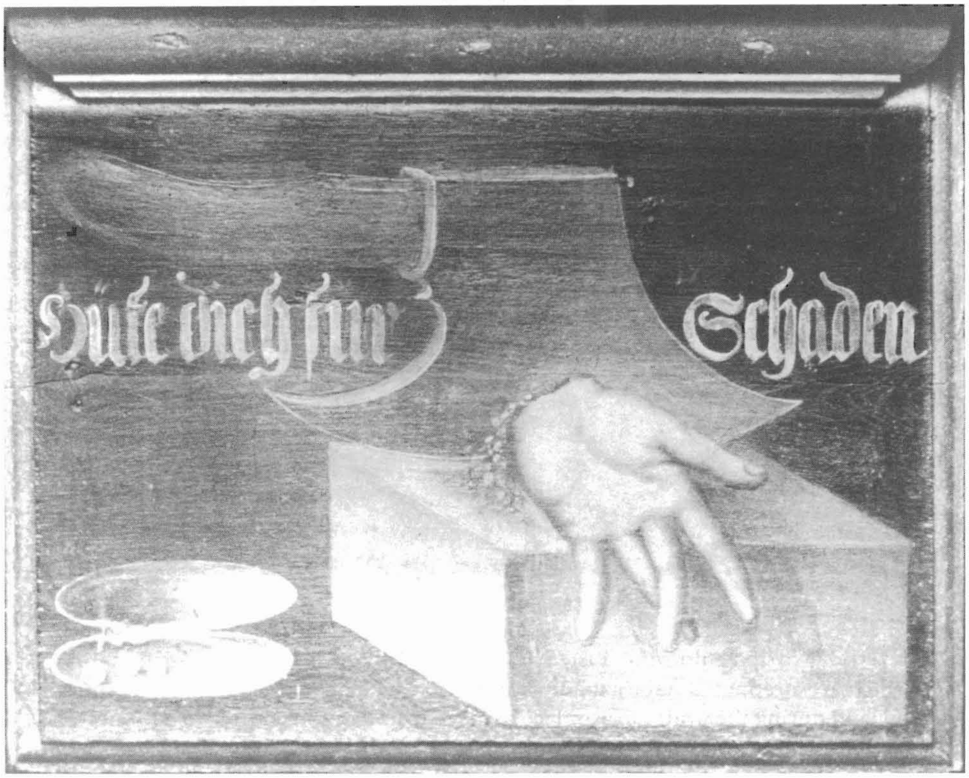

Figure 9
Warning to pearl mussel poachers (1736). The inscription reads: "Don't get yourself hurt." Poaching was generally punished by amputation of a hand (except in Bavaria, where poachers were executed by hanging), and similar signs were usually posted on river banks near pearl mussel stocks. For more than two centuries the sign shown here (a painted oak panel) kept guard over a stock in Schwienau Creek belonging to Ebstorf Monastery in northern Germany; it was finally removed in the 1950's (Original at Ebstorf Monastery; photograph courtesy of State Natural History Museum, Braunschweig).

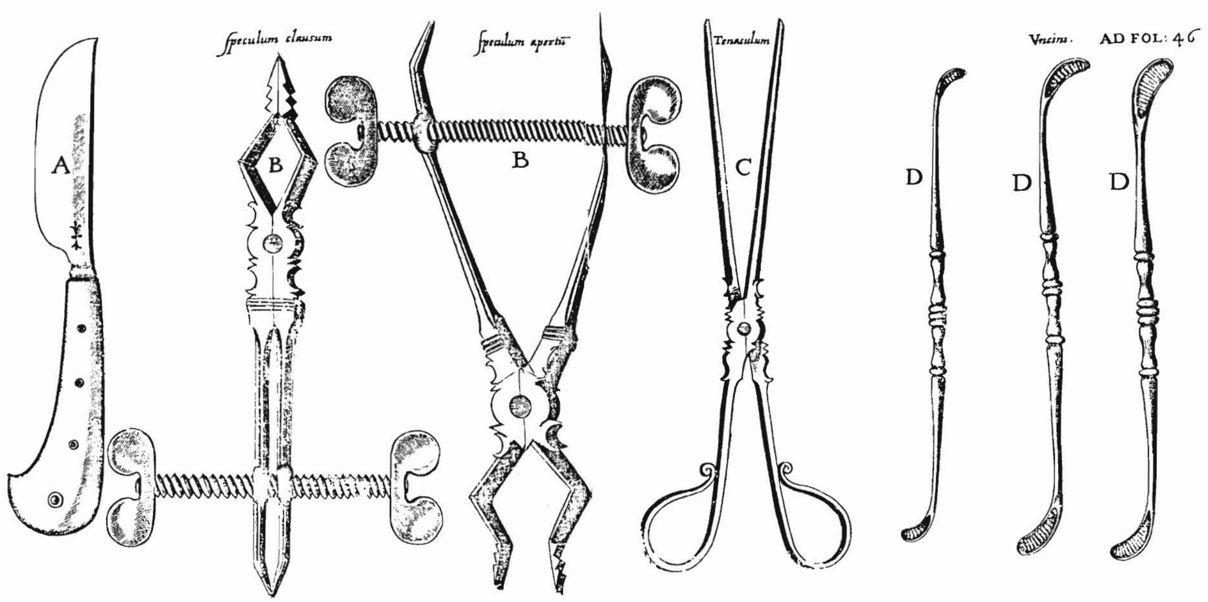

Figure 10
Instruments for the removal of pearls from live pearl mussels, developed in the 1630's by Malachias Geiger, physician to the Duke of Bavaria (after Geiger, 1637; reproduction courtesy of State Natural History Museum, Braunschweig).

Figure 11
Intertidal oyster culture at List/Sylt. The oysters are in bags of plastic netting which are strapped to tables made of iron rods. Oysters and tables must be stored on land during the winter to avoid ice damage (Photograph courtesy of Dittmeyer's Austern-Compagnie, List/Sylt).

Current Molluscan Production

The German molluscan fisheries and aquaculture sector (production and processing) now employs nearly 100 people year-round and another 50–100 seasonally. It creates additional jobs in the marketing and transportation sector, but the actual number of jobs is impossible to estimate. The annual value generated is about DM 50 million (US$30 million); in exceptionally good years, this figure may be more than twice as high.

Culture of Pacific Oysters

Cupped oysters, *Crassostrea virginica* and *C. angulata*, were introduced to the German Baltic Sea and Wadden Sea in the late 19th (Möbius, 1887) and early 20th centuries, and again between 1954 and 1964; the experiments were discontinued, however, mostly for economic reasons (Neudecker, 1990). Pacific oysters, *C. gigas*, were introduced in the early 1970's, and an experimental hatchery of the Federal Fisheries Research Agency was in operation in Langballigau (Flensburg Fjord) from 1978 to 1984. The salinity in Flensburg Fjord proved too low for succesful growout (Seaman, 1985), but several fishermen and small companies attempted commercial production off various Wadden Sea islands in the 1980's.

Only one company survived by 1992; it is located in List (Sylt), and its production is based on the import of half-grown oysters from the British Isles. The oysters are imported in spring and grown in sacks made of plastic netting, which are strapped to iron tables on the tidal flats (French "poche and table" method, Fig. 11); they attain marketable size (70–90 g) in 1–2 years. The standing stock is almost 2 million oysters, and annual sales total 1.2 million (company information). More than 1 million oysters are overwintered in land-based tanks to avoid the risk of total loss during ice winters. The company has 5–10 employees year-round; it uses additional labor at the time the stock is brought out to the flats in spring, and at harvest time. The enterprise began with an original investment of DM3 million (US$2 million), and its annual sales now total DM1.5 million (US$1 million). The oysters sell in restaurants for DM6 (US$4) apiece.

The company conducts monthly sampling for algal toxins (DSP and PSP), as well as for bacteria, both in the oysters and in the ambient seawater; tests for heavy metals and for organic pollutants such as PCB's are done twice a year. In addition, there are further standards to be met for a government quality certificate. The oysters are shipped in baskets made of plywood, which are packed with moist reeds, *Fragmites comunis*, and sold to restaurants and wholesalers throughout the country; they are usually eaten raw on the half-shell. Although they have a very high quality, the production method (the overwintering procedure, in particular) is also more expensive than elsewhere, and market competition with cheaper French imports is the main constraint.

Oyster consumption in Germany more than doubled during the 1980's, but is now stagnating at 700 t yearly. The German market is supplied mainly from France (400 t); imports from the British Isles and from the Netherlands, as well as German production itself, account for another 100 t each (Neudecker, 1991; Neudecker[5]). The oysters from Sylt are often preferred over the French during the summer, because they have a lower spawning activity, and the company has now recovered the original investment and is making a profit.

Blue Mussel Fishery

In the past two decades, the North Sea blue mussel fishery, reviewed by Ruth and Asmus (1994), has undergone further sophistication, whereas mussel production in the Baltic sector has ceased altogether. Evolution of the fishery has been stimulated by international developments, but it was also encouraged by a concerted management effort in the 1970's and 1980's, focusing on sanitation, marketing, and environmental aspects (Kleinsteuber and Will, 1976–86). The mussel fishermen in Lower Saxony have given up their mixed fishery in favor of a highly specialized mussel fishery. The surface area of the culture plots and the landings have risen steadily; boats have been modernized and new vessels (Fig. 12) have been built and, although the number of boats has decreased, the power and capacity of the fleet have become greater.

Coinciding with the trend toward specialization and modernization, the German mussel fishery has increasingly come under foreign control in recent years, even though the various companies are all based in Germany. At present, there are 14 boats in the fishery (6 in Lower Saxony and 8 in Schleswig-Holstein), but one is subject to restrictions. The six licenses (boats) in Lower Saxony are owned by three German fishermen (one license each) and one German-Dutch company, which holds the remaining three; in Schleswig-Holstein there are two German companies with one license each, as well as one Dutch-controlled and one British-controlled company with three licenses each.

The German mussel culture is an extensive bottom culture. The fishermen must submit an application specifying location and size of the culture plots; state authorities will grant the plot (at a nominal fee) if there is no conflict with other user groups. There are now more than 80 culture plots off the German North Sea coast; the size of a plot is between a few dozen and more than 100 ha (about 100–300 acres). Since 1990 the total culture area has remained at 2850 ha (7,000 acres) in

[5] Thomas Neudecker, Federal Fisheries Research Agency, Palmaille, 22767 Hamburg, Germany. Personal commun., 1992.

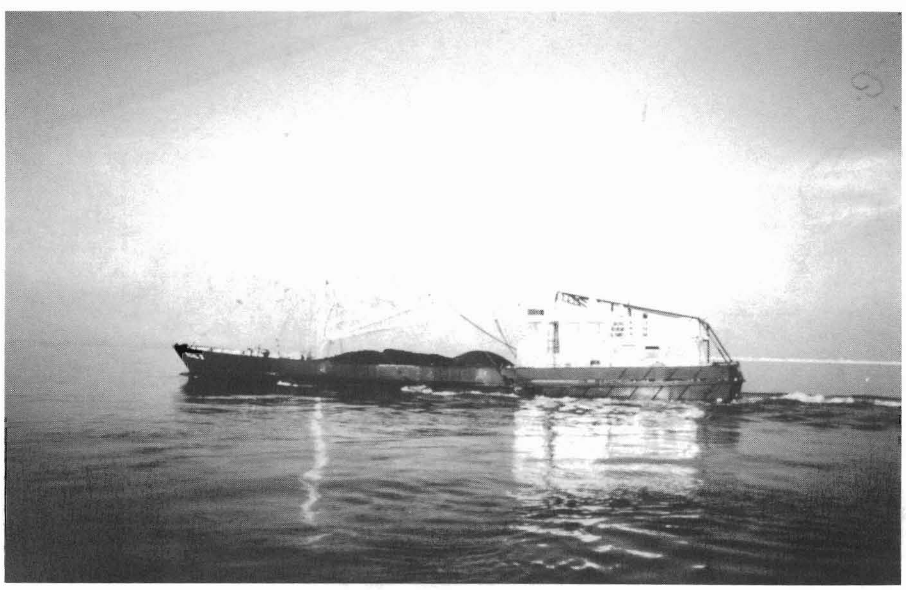

Figure 12
Mussel dredger *Ex Mare Gratia* from Schlüttsiel (Schleswig-Holstein), built 1987 in Husum. The boat is carrying a full load (Photograph by Maarten Ruth).

Schleswig-Holstein and 1012 ha (2,500 acres) in Lower Saxony.

Equipment—Significant technical improvements in the procedures used to spread small mussels from the boats onto the subtidal culture plots have contributed to the growth of the mussel fishery in recent years. Initially, the seed mussels had been shoveled overboard by hand, and later by mechanical grabs. The development of seeding procedures using conveyor belts reduced the manpower required, but maintenance costs were high due to wear and corrosion, and a high proportion of mussels were damaged during seeding. Today, the method used exclusively involves flooding holds to flush out the mussels through hatches below the water line by means of strong injector pumps (Fig.13); the seeding density is regulated by pump pressure and sailing speed of the vessel. The system requires little maintenance, and hardly any mussels are damaged in the process. On the other hand, it has led to an increase in the vessels' total displacement for a hold of equal size.

The typical boat today is about 35 m long, up to 9 m wide, has a hold capacity of about 100 m^3, and has a draft of 0.7–1.3 m unloaded and 1.5–2.3 m at full load. The vessels are powered by one or two diesel engines (total of 300–600 hp) and driven by one or two screws which are enclosed in a broad ring and sometimes protected additionally by steel screens on both sides. There are two holds (fore and midships), each equipped with an injector pump and mechanically operated hatches on both sides of the hull. The mast (frequently an A-shaped frame) is located in front of the holds. The vessels have four booms (one for each dredge) and the dredges are operated by six (frequently hydraulic) winches, one to operate the warp of each dredge and the other two to pull two dredges simultaneously over the hold and empty them. The central hydraulic pump is generally driven by a separate diesel engine.

A mussel boat is usually operated by a captain and a crew of two. The pilot bridge and (nowadays luxurious) accomodations are located astern. The pilot bridge is equipped with custom electronic navigation aids such as radar, GPS or Decca[6], navigation plotter, FM radio set, and cordless telephone. Color echo sounders are used to find subtidal beds and to examine possible locations for new culture plots. A dory is used for shallow-water operations, such as landing on tidal flats to search for intertidal beds.

Method of Extensive Culture—The fishermen seed their culture plots with mussels fished from natural beds (Fig. 14). The fishery typically removes only half of the

[6] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Figure 13
Mussel dredger: view of the dredges and holds. The pipe seen in the hold is used during the seeding procedure to pump water into the hold and flush out the mussels through lateral hatches below the water line (Photograph by Maarten Ruth).

actual mussel biomass of a mature natural bed with a mixed age distribution (Schirm, 1991); a higher proportion may be captured on dense beds of juveniles or in years when the standing stock is small and market demand is high. Daily catches are normally about 100–150 t, including so-called "tara" (i.e. empty shells, stones, mud, and bycatch), which represents a full hold. On dense subtidal beds or culture plots with sufficient water depth at low tide, the boat hold can be filled in 5 hours and, if the wild bed or culture plot is located close to the landing site (which is the exception), the daily catch can be doubled. Although subtidal stocks are generally preferred, they hardly exist in Lower Saxony; the reasons are unclear.

In the case of intertidal stocks and on low density natural subtidal beds the catch per unit effort is much smaller; the economic limit depends on market prices and on the amount of stock on the culture plots. The situation during the spring of 1990 provides a good example. At that time, there were no subtidal beds in Schleswig-Holstein, most of the culture plots were empty, and dense intertidal beds were missing due to recruitment failures in previous years; prices promised to hit record highs, and the fishermen fished on the remaining intertidal beds until the catches per flood tide fell below 30 t (including up to 50% tara).

The mussels from wild stocks seldom have the meat content required for immediate marketing. After being fished from a natural bed, the mussels are often kept in the hold for a few hours, sometimes in fresh water or with added salt, to kill noxious organisms such as starfish. Half-grown mussels (20–50 mm shell height) are seeded at densities of 100 t/ha; so-called seed mussels (5–20 mm shell height) are relayed at densities of 30–40 t/ha (these weights include tara, i.e. bycatch organisms, shells, mud, and stones). The success of a culture strongly depends on careful seeding; it may take up to 5 hours to spread 100 t of seed evenly across a plot.

Adequate culture sites must have good growing conditions, low storm risk (shelter of islands or sand banks), low ice risk (sufficient depth), stable bottom without moving sands, and a low probability of massive impact by predators (e.g. starfish, eider ducks) or other detrimental organisms (e.g. barnacles). Tidal currents should not exceed 1 m/second. Most of these factors are highly variable, and the fishermen try to offset the risk of unfavorable conditions in one particular subarea by distributing their plots as widely as possible. In Schleswig-

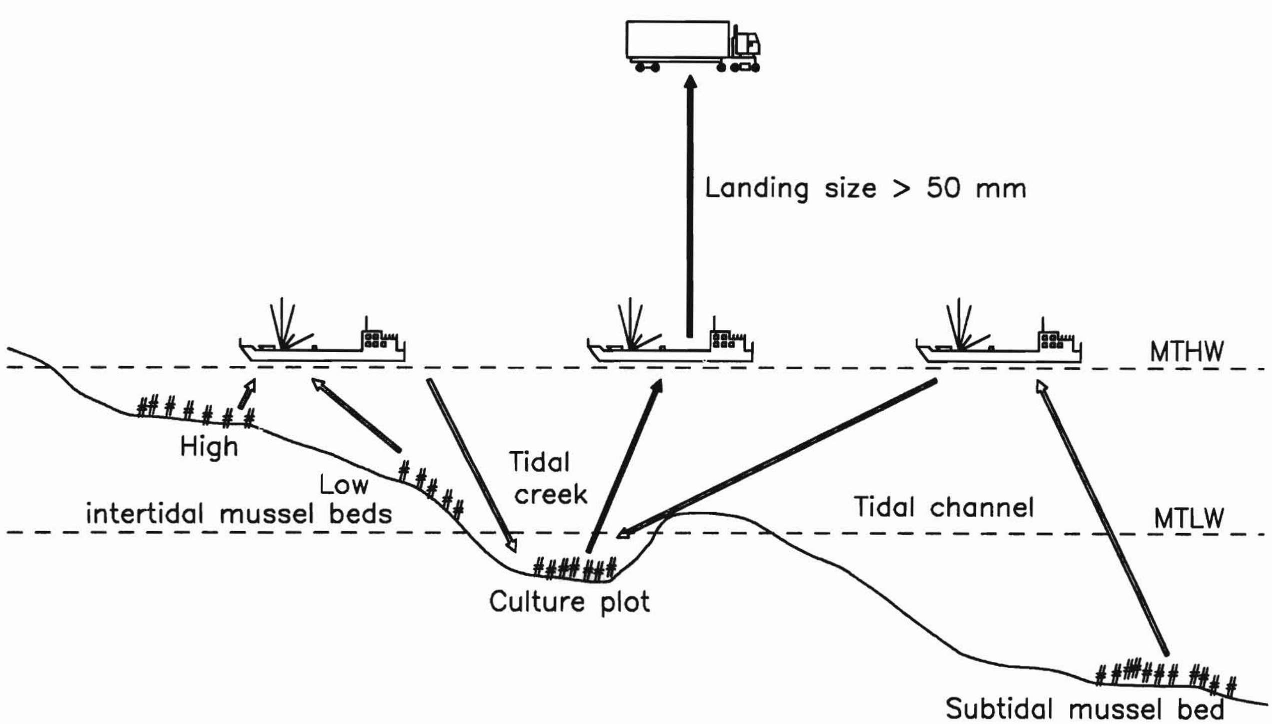

Figure 14
Diagram of the mussel cultivation procedure. Mussels are fished from wild beds, relayed on culture plots, and later fished again for landing.

Holstein all plots are subtidal, at depths of up to 10 m below the high-water mark; they are located in the region north of the Eiderstedt Peninsula. In Lower Saxony most of the culture plots are just above the low-water line, in the sheltered sector west of the Weser Estuary.

At good locations small mussels attain the meat content and size (well over 50 mm) required for marketing within 1–2 years. After harvest the plots are cleaned of remaining empty shells, starfish, mud, and pseudofeces deposits before reseeding. A good plot will return more than 100 t of mussels per ha (1,500 bushels/acre) including tara, and the yield is generally higher than the quantity seeded originally (in the Netherlands the yield-to-seed ratio is <1, because Dutch regulations until recently forced the fishermen to seed with haste, and because the large number of licenses that have been granted leads to the use of many less desirable sites, and to frequent relaying of stock).

Management and Regulations—The fishing licenses are the prime tool for managing the German mussel fishery. They are granted by the state governments for a period of 1–3 years, but the fishermen have no legal rights to be awarded licenses or to have them renewed. Any new regulations can be introduced and enforced by the state governments at will, particularly because the license conditions can be changed and the licenses can be revoked at any time. Laws and regulations are reviewed in CWSS (1991).

In Lower Saxony, the state reserves the right to impose restrictions on the fishing season, allowable catch, and fishing sites. The fishermen must inform the authorities about the natural beds on which they intend to fish; the beds between the polluted Elbe and Weser estuaries are closed to the fishery, and the other beds are opened only after the authorities have confirmed their safety. Although the size of the culture plots has been frozen at present levels, there are no catch limitations. Minimum size of mussels for the consumer market is 50 mm (10% undersized mussels, calculated by live weight, are permitted), and maximum size for seed is 40 mm (10% oversized permitted); relaying may only occur within the boundaries of the state. Mussels from culture plots may be landed year-round; wild beds may be fished only from 1 October to the end of February, but exceptions for the seed fishery are possible between 1 March and 15 June. Controls of minimum sizes, fishing areas, and fishermen's catch records are relatively frequent.

In Schleswig-Holstein, new regulations took effect in January 1996, and the State Fisheries Agency now employs a biologist concerned exclusively with monitoring the mussel fishery. There are no geographical restrictions or catch quotas, but the landing of mussels is forbidden from 15 April to early July (the precise date being set to coincide with the beginning of the fishing season in the Netherlands). The boats are operated under exemptions from the laws decreed in 1950–53; the number of licenses has now been definitely limited to eight. The fishermen have voluntarily relinquished the cultures located in "Zone 1" (the most protected area) of the National Park, and traded them in for sites in "Zone 2" (Fig. 15). Culture sites are granted by the State Ministry of Agriculture after consideration of other interests (shrimp fishery, navigation), and the overall surface has now been limited to 2,800 ha (7,000 acres). Minimum landing size is 50 mm (20–40% undersized mussels, calculated by live weight, will be permitted; this is subject to ongoing negotiations). Mussels from wild beds may no longer be sold on the market; they may be fished year-round, but exclusively to seed culture plots in Schleswig-Holstein, where they must remain for the duration of at least one growing season. The fishery on intertidal beds has been banned altogether, and the fishery in subtidal areas of "Zone 1" is permitted only when seed mussels are not to be found elsewhere.

Until 1996 the fishermen worked almost without government supervision, and only their adherence to the size regulations was checked a few times a year. There are no reliable economic and production data, because the catch statistics are derived from the fishermen's records and estimates, and because profits and losses of the international companies can be easily manipulated between the German daughter firm and the foreign parent. To better oversee the companies' activities, the State of Schleswig-Holstein has also introduced new reporting regulations in 1996, including an electronic surveillance system (see "Outlook" section).

Shellfish sanitation was rarely an issue in Germany in recent decades until the first massive outbreak of diarrhetic shellfish poisoning (DSP) in 1986 (Meixner and Luckas, 1988), which had a strong (but temporary) market effect; paralytic shellfish poisoning (PSP) has never been recorded in German waters. Health and quality tests are now conducted before and during the fishing season by various government laboratories. Before the season opens, both states analyze the mussels for bacteria, algal toxins (PSP and DSP), heavy metals (lead, cadmium, and mercury), and radioactive nuclides; in Lower Saxony, the mussels' gross chemical composition and their hydrocarbon (HCH and PCB) content are also analyzed and, in Schleswig-Holstein, bacterial concentrations in the seawater are determined. During the mussel fishing season, Lower Saxony measures algal toxins biweekly, and controls following the "European Community Regulations for Shellfish Water Quality" are conducted every 3 months. In Schleswig-Holstein, algal toxins and bacteria in the mussels are determined weekly during the fishing season. Both states have routine monitoring programs for noxious algae in

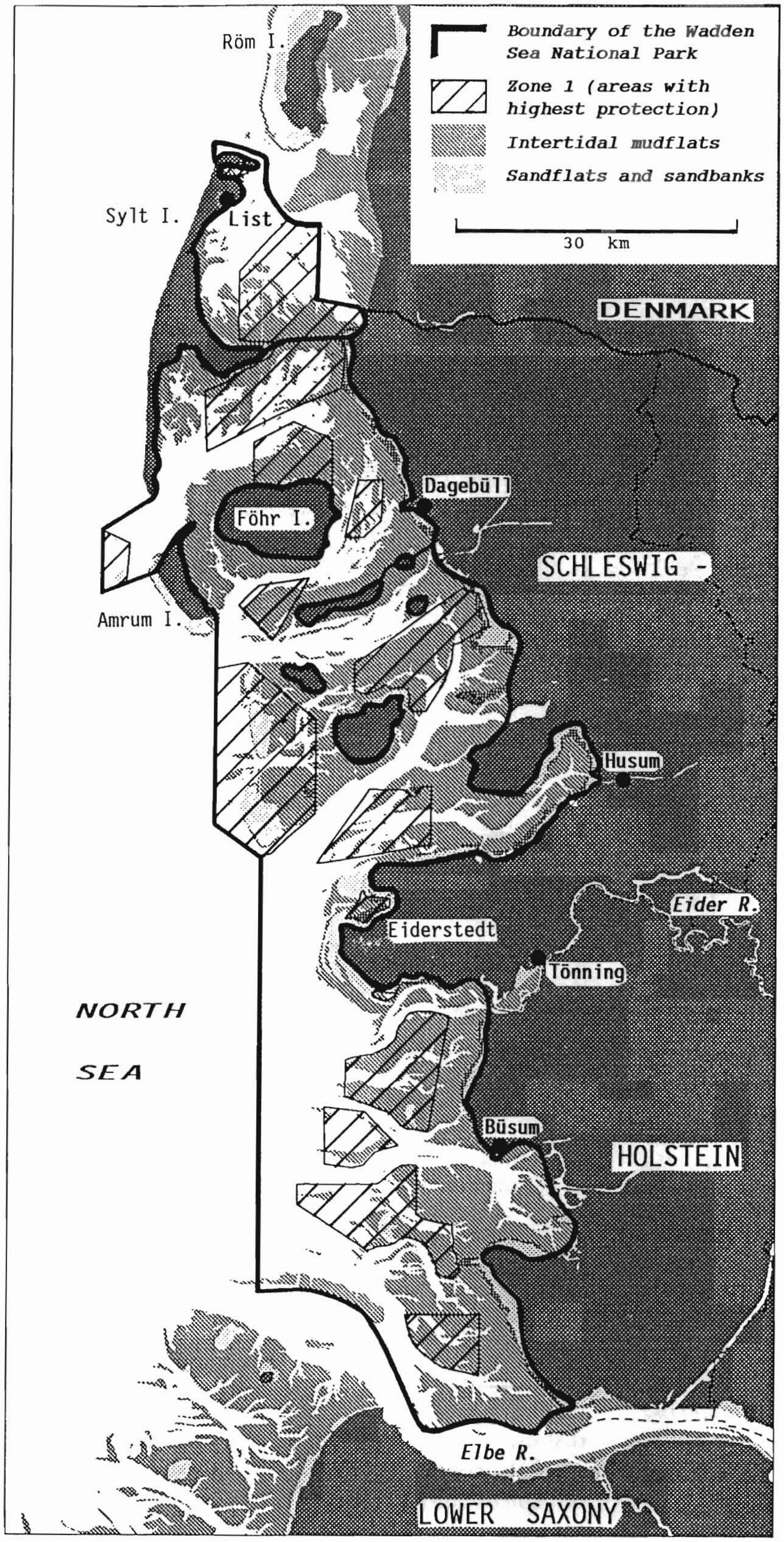

Figure 15
The Schleswig-Holstein Wadden Sea National Park. The isolated areas enclosed by solid lines represent "Zone 1" with the highest protection status. The structure of the Wadden Sea and of the corresponding national park in Lower Saxony are similar. Original map by the National Park Agency for the Schleswig-Holstein Wadden Sea, Tönning.

coastal waters. To prevent the introduction of diseases, Schleswig-Holstein enacted a new regulation in 1996, prohibiting mussel boats from entering or leaving the state's waters without prior official permission.

Marketing—When it is landed, the catch is loaded with a mechanical grab directly from the ship's hold onto trucks (about 5% of the mussels are destroyed in the process); this procedure precludes the use of refrigerator trucks, because they cannot be loaded from above. The trucks reach the most distant market, Italy, within 36 hours; shorter distances (e.g. to the Netherlands) are covered overnight. Most German mussels are sold fresh to wholesalers from the Dutch mussel center in Yerseke, who depurate them in large saltwater ponds and then process or resell them. The remaining landings are sold on the German market, as well as to wholesalers in Belgium, France, and Italy. Half-grown mussels may be sold directly to Dutch fishing companies (often the parent companies of German firms) as seed for their plots. Seed exports to the Netherlands were particularly important in the 1991–92 season, attaining 40,000 t (tara excluded). Landings and average prices[1] are shown in Figures 16 and 17.

When the wholesale price in Yerseke is very high the German catch goes almost exclusively to the Netherlands, and most of the fresh mussels sold on the German market are then imported from the Danish Limfjord (for various reasons, the Limfjord mussels are considered low in quality by the Dutch industry). On the other hand, some of the German fishermen traditionally sell their mussels in the population centers of western Germany (Rhine/Ruhr area), and one fisherman has an extensive marketing organization with up to 40 seasonal employees here. In years when the Dutch catches are high, however, the Germans may suffer intensive competition on the Rhineland market from the aggressive and well-organized Yerseke traders.

Consumer preference is for large mussels (>20–25 g live weight) with clean shells (even mussels with mechanically removed barnacles are difficult to sell to Belgian and French consumers), and high meat content (ratio of cooked meat weight to live weight >30%) with "white" meat (indicating low spawning activity); the French market will also accept smaller mussels. Other quality criteria are general appearance, taste, and smell. Insufficient market supply reduces the standards for acceptability, besides increasing the price. High quality mussels are generally sold fresh, mostly to restaurants, where they are boiled in water with spices, and eaten from the shell; except on the coast, mussels are rarely cooked by private households. Lower quality mussels are processed, which involves removal of sand, freezing or cooking, and packaging. Frozen mussels are sold to restaurants, which use them for a variety of dishes, or added to deep-freeze menus sold in supermarkets; cooked meats are sold in glasses, with or without spices, and often used for salads.

Germany has two processing plants with 40–100 employees each (depending on the season), both situated

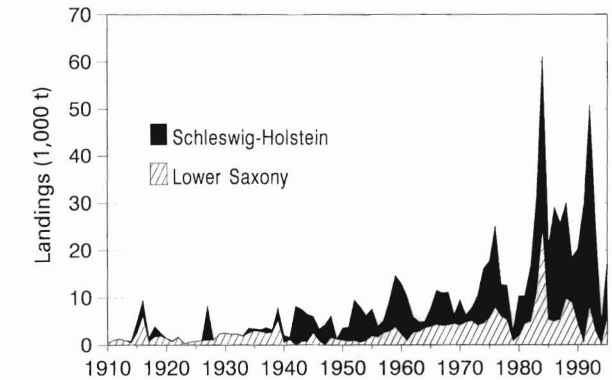

Figure 16
German blue mussel landings (in thousands of tons fresh weight) from 1910 to 1995. Official data from annual reports of the State Fisheries Agencies. The figures include 20–40% "tara" (bycatch, empty shells, mud, and stones) until the late 1980's; figures for recent years represent net weight of the sold catch (clean product). In general, the catch consists predominantly of large mussels for the consumer market; in 1991 and 1992, however, the landings were largely composed of seed for export to the Netherlands.

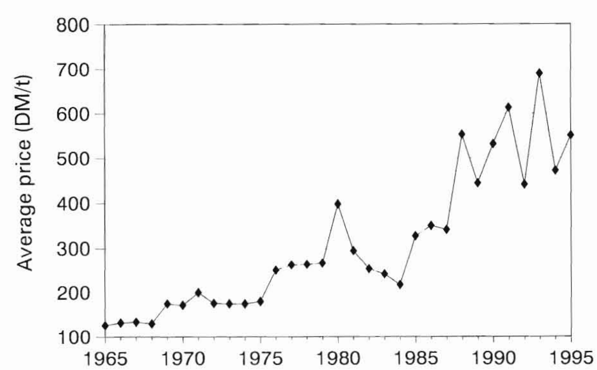

Figure 17
Average prices for blue mussels from 1965 to 1995 as calculated from official data in the annual reports of the State Fisheries Agencies. Auction prices in Yerseke (Netherlands) are better indicators of the market situation; e.g., auction prices of fresh mussels for the consumer market doubled from 1991 to 1992, but this is not reflected in the German data, which consisted mostly of half-grown mussels for reseeding on Dutch beds.

in Schleswig-Holstein. They are run by a British and a Dutch-controlled company. To promote the local economy, the state government has linked the mussel licenses granted to foreign-controlled companies to the operation of these plants, but both process mostly imported Danish mussels, because the German catch commands a better price in the Netherlands.

Economics—German retail price to consumers is about DM5.00/kg (US$1.50/lb), but prices vary widely during the year. At the Dutch mussel auction center of Yerseke, wholesale prices are highest at the beginning of the season in July, due to the high demand from Belgium at the beginning of the Belgian vacation season. Because of seasonal restrictions in Germany (particularly in Schleswig-Holstein), most of the German catch has not really reached the retail market until September, when prices were already declining; the new seasonal regulations enacted in 1996 should improve the profitability of the German fishery.

Price fluctuations are additionally affected by peculiarities of the market (Gibbs et al., 1994). In July 1992, for example, wholesale prices for top quality fresh mussels at Yerseke attained DM5.80/kg (US$1.70/lb), but the consumers did not accept the price increase. The dealers were unable to sell the merchandise and a lot of high-quality mussels had to be processed at a loss. Dutch wholesale prices consequently plunged at the beginning of the season and then stabilized below DM1.50/kg (US$0.40/lb); seed prices in 1991–92 were about half as high, attaining about DM800 (US$500) per ton (all wholesale prices are only estimates, because the transactions involve a lot of deal-making and exchanges of nonpecuniary favors).

The price of a new mussel boat exceeds DM3 million (US$2 million), and the operation costs for the vessel (including salaries for the crew, equipment repairs, depreciation, etc.) are about DM1.5 million (US$1 million) per year. A profitable operation requires annual landings of nearly 2,000 t per boat, but the catch fluctuates greatly from one year to the next. The combined landings of the Netherlands, Germany, and from the Danish Wadden Sea have been relatively stable during the past several decades, as low catches by one country were compensated by high landings of another, and rather than reflecting the state of the stocks on culture plots and natural beds, German mussel production is largely determined by the market situation in the Netherlands (which depends on the Dutch catch).

New Offshore Fishery for Hard Clams

In 1992 a large stock of hard clams, *Spisula solida*, was discovered about 10 n.mi. west of Amrum Island, and the fishermen have since found a series of hard clam beds all along the German North Sea coast. A 1975 study of the benthic macrofauna of the German Bight (Salzwedel et al., 1985) found only isolated beds of *Spisula solida*, and Meixner (1993) roughly estimates that the entire hard clam population had a biomass of 100,000–150,000 tons at that time. In 1992–93 the stock off Amrum, which is spread over several km^2, was estimated at about 100,000 t, and all the *Spisula* stocks probably added up to far more than 200,000 t (Ruth, unpubl. data). This implies a significant increase in biomass, and it would also mean that the hard clam population is superior in size to the stocks of blue mussels, which presently provide the mainstay of the German molluscan fishery.

The *Spisula* stocks are located partly within and partly beyond the Wadden Sea boundaries. The former fall under the jurisdiction of state authorities, which have granted six licenses to different companies. The latter fall under the jurisdiction of the European Union (EU), and are not subject to any regulation whatsoever; thus any fishing boat from a EU member country is allowed to catch offshore clams without restriction. The clam beds, which are also frequented by shrimp fishermen, are situated on banks of coarse sand at depths of about 10 m. The clams attain a maximum size of 45 mm at 7 years of age; in commercial catches they are 2–5 years old and have a size of 35–43 mm. Their flavor is excellent, and their meat content (20% cooked weight) is intermediate between cockles (13%) and mussels (30%). The clams disappear from the fishery from November to May, but this also is a common phenomenon in the *Spisula* fishery off the U.S. Atlantic coast. Presumably, the clams are out of reach of the dredges, because they dig in deeper and the soil hardens[7]; this assumption is supported by the fact that the catch per unit of effort decreases progressively during October while, at the same time, the number of broken clams in the dredge increases. Despite the temporary disappearance, there does not seem to be any serious winter mortality.

The boats employed are regular cockle dredgers; they use one modified hydraulic dredge (Fig. 18) that has pressure and suction pipes almost 40 m long. The dredge is set for maximum penetration into the sediment (6–7 cm). Bycatch organisms (mostly sandeels, flatfishes, and other bottom-dwelling fishes, as well as various crustaceans and bivalves) represent less than 1% of the weight of the catch. The fishing trips normally last 1 day. Due to the exposed locations, wave action at wind speeds higher than 4–5 Beaufort leads to damaged pipes and dredges, and the fishery can only take place 30–40 days per year. The catch (5–8 t/hour) passes directly from the exit of the suction pipe through

[7] Clyde L. MacKenzie, Jr., NMFS James J. Howard Laboratory, Highlands, NJ 07732. Personal commun., 1992.

a rotating drum for sieving and culling, and then proceeds onto a conveyor belt which empties into the hold. Clams for the frozen market are watered on board in tanks of 2–3 m^3 to allow them to eliminate the sand; the watering process is omitted when the catch is destined to be cooked, because the sand can be eliminated by thorough rinsing of the cooked meats.

The catch was initially shoveled by hand into wooden boxes and later transferred to refrigerated trucks. This was too time consuming and labor intensive, however, and the procedure followed now is the same as in the mussel fishery, i.e., the contents of the hold are loaded onto trucks with mechanical grabs, despite the fact that a higher proportion of clams is damaged by the procedure. The clams are landed at the ports of Harlingen (Netherlands), Havneby (Denmark), or Dagebüll (Germany), processed in the Netherlands, and sold to Spain and Italy. The official landings[1] from Germany (Table 3) are underestimates. The total landings of clams from the German coast were probably about 5,000 t in 1993 (Meixner, 1994), and well over 10,000 t in 1995 (including Dutch vessels fishing in EU waters). The price data are similarly unreliable, e.g., the clams are two orders of magnitude more expensive on the Spanish retail market, and the price to producers must therefore be much higher than given in Table 3.

Outlook

Most shellfishery activities are subject to substantial legal constraints and environmental pressures, such as those which led to the ban of the cockle fishery. Any new fishery or expansion of an existing fishery in the Wadden Sea will probably be blocked by pressure from environmental groups, and further growth of the molluscan fishery appears possible only in offshore areas situated beyond the limits of the National Parks. The following gives an estimation of the German production potential, and of the possible evolution of the German molluscan fisheries, although we must admit that developments are often too sudden and surprising to allow reliable prognostication.

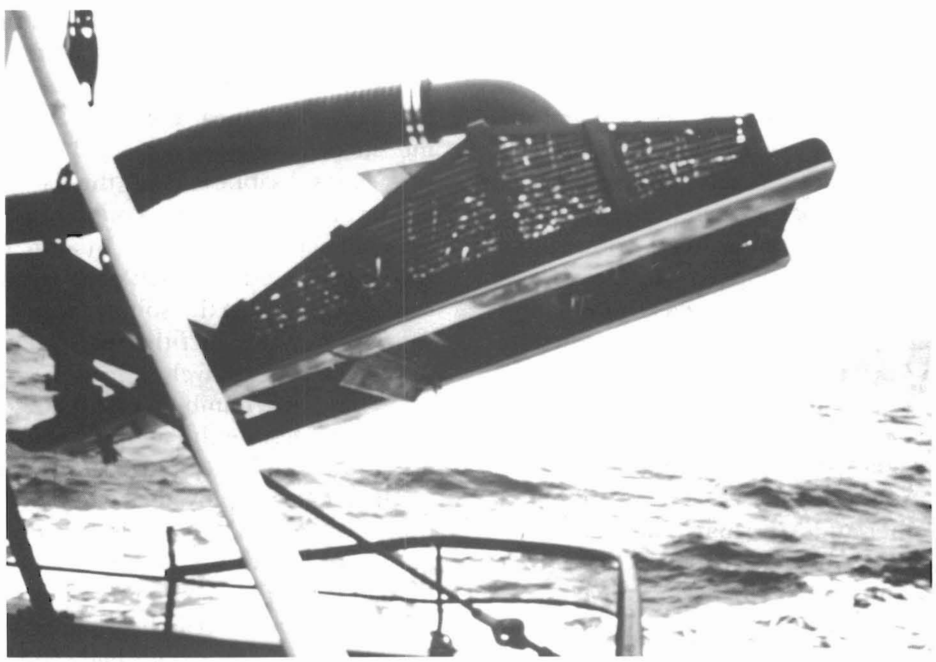

Figure 18
Hydraulic suction dredge used in the large-scale fishery for burrowing bivalves such as cockles and hard clams. On top of the opening of the dredge (left) is the pressure pipe, from which water is ejected at high pressure through a slot-shaped nozzle in order to disperse the sediment. The knife underneath (between the rails) lifts remaining sediment and clams into the cage; the penetration depth of the knife is adjustable. The catch is sucked into the suction pipe (top), is carried upward through the impeller of the vacuum pump, and is emptied aboard the ship into a rotating drum sieve (Photograph by Maarten Ruth).

Table 3
Landings and prices of hard clams, *Spisula solida*, in Germany (official data of the state fisheries agencies; some of the landings were cooked meat, and these have been converted to raw catch by multiplying by 5).

Year	Catch (t/year)	Price (DM/t)
1992	426	690
1993	1,301	370
1994	1,463	230
1995	7,314	230

Oyster Culture

Culture of Pacific oysters, *Crassostrea gigas*, has proven economically feasible in Germany, as long as it is conducted on a large-scale professional basis. Although the more expensive production method (land-based overwintering) is largely compensated for by the German oyster's high meat content, a reduction in production costs will still be necessary to make the German oyster truly competitive. There are some excellent potential sites along the German North Sea coast, and the annual oyster production could theoretically be expanded to several thousand tons if German consumer demand increased further or if the French market became accessible.

Present statutes forbid the introduction of exotic species into the Wadden Sea, whereas the culture depends exclusively on foreign imports of half-grown oysters. The authorities have, in practice, been treating Japanese oysters as an endemic species, because they were first introduced before the new regulations came into effect. Any proposed expansion of culture activities, however, would have to overcome resistance from other interest groups, such as environmentalists. On the other hand, a natural population of *C. gigas* has now finally established itself in the southeastern North Sea—two decades after the species' first introduction—ultimately leading in 1994 to widespread recruitment in the northern part of the Wadden Sea (Reise and Ruth, manuscr. in prep.). This second stock spawned in 1995, and its development should open a long-range perspective for Pacific oyster culture in Germany.

Blue Mussel Fishery

Annual catches have always undergone strong fluctuations, and this will remain so in the future. The latest decline in German landings resulted from a paucity of seed mussels, but it does not represent any fundamental change in the fishery itself. Environmental regulations and objections by the shrimp fishery will prevent any further expansion (number of licenses and total surface of culture plots). There are demands to further extend "Zone 1" (Fig. 15) and these may lead to the closure of considerable parts of the Wadden Sea to the fishery, with a subsequent reduction of landings. In addition, the diminishing eutrophication of the North Sea (due to the expected reduction of nutrient inputs) may also result in a decrease in productivity (Boddeke and Hagel, 1991). The present National Park statutes, however, do offer a secure perspective, and they will force the fishery to become more efficient in the long run (Ruth, 1991, 1992, 1993a, b).

The regulations introduced in Schleswig-Holstein in 1996 (such as the ban of the fishery in intertidal areas and in "Zone 1") completely fulfill the demands of environmental organizations. In addition, the Schleswig-Holstein fishermen are now required to report to the Fisheries Agency on a daily basis (geographic location and time of day of their fishing trips, weight and quality of the catch, seeding activities, etc.), and they will also have to install electronic devices to allow the authorities to monitor their ships' activities in detail, thus providing a solid basis for management and control of the fishery.

Environmentalists continue to criticize the mussel fishery, however, and some of them would probably like to see it banned altogether. Their demands for quotas and catch limitations must be rejected; stiff limits would cause enormous economic losses to the fishery in good years, and flexible limits are impractical because stock size fluctuates too strongly and too abruptly (Nehls and Ruth, 1994a,b). For example, in the case of an exceptionally strong local recruitment, a prolonged intensive seed fishery at the site of the spatfall greatly improves growth and survival of the remaining unfished juveniles by spreading them over a larger area and by reducing the local population density; this immensely increases the total biomass of seed mussels and enables the fishermen to stock their cultures with maximum economic profit and minimum use of ecologically sensitive intertidal beds.

Hard Clam Fishery

The new fishery at first merely provided some compensation to boats which had been grounded by the ban on cockles. By 1995, the fishermen succeeded in overcoming initial difficulties in processing and marketing, and the clam fishery was beginning to surpass the mussel fishery in economic importance. The stocks, however, were wiped out completely in the first months of 1996, when the most severe winter conditions in 33 years (–1°C and 36‰ salinity in the bottom water) persisted until

April. The size of the *Spisula* stocks was probably the result of a succession of strong recruitment events during the past several years. The clam population had an evenly mixed age distribution, opening prospects for a prolonged sustainable fishery. Considering that the official landings for 1995 represent the catch of only two vessels within the 12 mile zone (the other four boats did not exercise their licenses), the hard clam fishery is potentially much more profitable than that for blue mussels.

It is impossible to predict whether the hard clam stocks will recover, as has been the case with blue mussels, which frequently suffer high winter mortalities and always offset them by strong recruitment a few months later. In addition, the clam fishery faces various other constraints. It has now begun to attract the attention of environmentalists. Judicious management of the fishery will remain an impossibility for years to come, because the Federal government has relinquished its authority over the stocks, which now fall partly under regional and partly under European jurisdiction. A scientific assessment is long overdue, but proposals for a study of the stocks and the fishery have fallen prey to budget limitations on the part of the responsible government authorities. Germany is the only country with a hard clam fishery which has not conducted a survey, and we do not expect one to be carried out in the foreseeable future. Despite its enormous potential, the German *Spisula* fishery's future can only be characterized as completely uncertain.

Unexploited Stocks

Squids, *Alloteuthis subulata* and *Loligo vulgaris*, constitute part of the bycatch of the finfisheries in the German Bight. The annual catch is in the order of 10 t, but most of it is either discarded overboard or goes into fishmeal production, and only a few hundred kg per year are landed[8]. The stocks seem to have been increasing in recent years (Steimer, 1993), but an increase in landings is not expected.

Whelks, *Buccinum undatum*, are abundant locally, but the stock has never been studied. The toxic effects of tributyl tin (TBT) on whelk reproduction may have led to a decline of the population in recent decades. Past experience, and the fact that whelks are also K-strategists which reproduce slowly (Gendron, 1992), suggest that even a small-scale fishery (e.g. for export to southern Europe) could not be sustained.

Softshell clams, *Mya arenaria*, continue to be abundant in the Wadden Sea, but an exploitation of the stocks is not to be expected, due to the absence of a market, as well as environmental constraints (the stocks are within the limits of the National Parks, and a modern fishery would have to employ hydraulic dredges with deep penetration into the sediment).

Cockle, *Cerastoderma edule*, stocks would easily support a highly profitable fishery, but the present ban will remain in effect in the foreseeable future.

Atlantic jackknife clams, *Ensis directus*, have become extremely common in the Wadden Sea since their appearance in the late 1970's. They were presumably introduced accidentally with the ballast water of tankers (Essink, 1986). The clams have an excellent meat content and their retail market price is DM28/kg (US$7.50/lb). The stock has not been studied until now. Part of it is located outside of the Wadden Sea proper, and is therefore not subject to the restrictive National Park regulations. A fishery with methods used elsewhere (e.g. Scottish mechanical dredges[9]) may well be feasible, and the companies engaged in the hard clam fishery have also applied for Atlantic jackknife clam licenses. A fishery on *Ensis*, however, might well lead to new conflicts between environmental and economic interests. The next developments will probably depend on the immediate market situation.

Ocean quahog, *Arctica islandica*, and horse mussel, *Modiolus modiolus*, stocks in the North Sea are not very important and undergo continuous destruction by the beam and bottom trawls of the finfisheries (de Groot and Lindeboom, 1994). A fishery of either stock is unfeasible[10]. In the Baltic Sea, natural production of ocean quahogs probably far exceeds 100,000 t/year, but the quahogs grow and reproduce slowly, and they are subject to intensive predation by fishes as well as destruction by trawls (Brey et al., 1990; Rumohr and Krost, 1991). An attempt at a fishery by one fisherman in Schleswig-Holstein in the early 1980's was quickly given up[11]. The feasibility of quahog aquaculture (e.g. Kraus et al., 1992) has not been studied in Germany.

In the Baltic Sea, various attempts in recent years to use the mussel and cockle stocks off the coast of Mecklenburg have been abandoned. Mussels, for instance, may attain densities of 10 kg/m^2, but less than 10% of the natural population reaches market size (40 mm); in culture on ropes, less than half of the mussel biomass attains market size within 2 years (Böttcher and Mohr, 1991). On the east coast of Schleswig-Holstein (where salinities are higher), between 400 and 500 t were landed in 1986 and 1987, but this fishery was

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[9] Eric Edwards, Shellfish Association of Great Britain, Fishmonger's Hall, London, England. Personal commun., 1992.

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abandoned in 1989. Fishery and culture activities could only become economically attractive again here if the Wadden Sea mussel fishery has a major crisis, which appears unlikely at present.

Concluding Remarks

The historical record shows that user conflicts are nothing new to the molluscan fishery (and they were definitely more dreadful in the old days), and management of these fisheries has a tradition spanning at least three centuries. Today, political controls on the shellfisheries may often appear excessive. It should be kept in mind, however, that at the turn of the century the pearl mussel fishery was destroyed by the lifting of management regulations and by environmental degradation, and that the traditional oyster fishery in the Wadden Sea failed despite all regulation, stock enhancement, cultivation, and biological research efforts. This experience should be a stern warning to those involved in present-day molluscan fisheries and in the management of this valuable resource.

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Molluscan Fisheries in Britain

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ABSTRACT

Mollusks, particularly oysters, *Ostrea edulis*, were an important source of food and employment for British fishermen as far back as the Roman occupation, and oysters were once a staple part of diets in poorer sections of the coast. In the early 19th century, oyster dredging from sailing smacks expanded and oystering became one of Britain's largest fisheries; production peaked in the mid–1800's. Blue mussels, *Mytilus edulis*, also have had a long history of use. Other species, such as cockles, *Cerastoderma edule*, and scallops, *Pecten maximus* and *Chlamys opercularis*, are harvested from wild stocks along with the periwinkle, *Littorina littorea*, and whelk, *Buccinum undatum*, that are often harvested in remote areas. Molluscan fisheries are distributed all around the British coastline. Harvesting methods range from hand gathering of periwinkles, raking of cockles, and potting whelks, to dredging for oysters and scallops and suction dredging for cockles. In England, mussel farming is growing; seed mussels are transplanted from natural beds to "lays" in sheltered areas for growth. In Scotland, mussels are being farmed, using rafts and longlines, and Pacific oyster, *Crassostrea gigas*, production is expanding. Hatchery production of Pacific oysters was developed at Conwy, North Wales. Commercial hatcheries now produce up to 100 million juvenile Pacific oysters/year. The most important mollusks landed by weight are cockles (20,000 t), scallops (17,000 t), and mussels (10,000 t), with scallops being the most valuable. Cockles and mussels are eaten locally, but most scallops are sold on the continent, mainly France. The interest in mollusk farming is growing, including nonindigenous species, such as the Pacific oyster; Manila clam, *Tapes philippinarum*; and northern quahog, *Mercenaria mercenaria*, but management of wild stocks to control exploitation will have vital importance in the future.

Introduction

For generations fishermen have exploited Britain's large molluscan resources to gain a livelihood. Records going back as far as the Roman occupation prove that mollusks, particularly oysters, were a valuable source of food.

Around British coasts a wide variety of molluscan shellfish (bivalves and gastropods) have been harvested from estuaries and shorelines to deep water. Some bivalve mollusks, such as the native oyster, *Ostrea edulis*, and the common mussel, *Mytilus edulis*, have a long history of cultivation. Other species, such as cockles, *Cerastorderma edulis*, and two species of scallops, *Pecten maximus* and *Chlamys opercularis*, have been taken from wild stocks and their fisheries have suffered wide catch fluctuations. Gastropods, such as the periwinkle, *Littorina littorea*, and the common whelk, *Buccinum undatum*, form the basis of local fisheries, often undertaken in remote areas, but valuable to the local population.

In an industry distributed all around the British coastline a wide variety of traditional methods have been used to harvest mollusks. These range from hand-gathering of winkles and raking of cockles on the shores to dredging for oysters and scallops in deep water and suction dredging for cockles in shallow estuaries.

Nowadays in Britain there is a growing emphasis on farming mollusks rather than just exploiting wild stocks. The growers are concentrating on oysters and mussels, and there is both experimental and commercial production of clams and scallops, including the use of nonindigenous species such as the Pacific oyster, *Crassostrea gigas*; Japanese littleneck or Manila clam, *Tapes philippinarum*; and the American hard clam or northern quahog, *Mercenaria mercenaria.*

Extensive research on mollusks after 1950 by the government's Fisheries Departments has led to a greater emphasis on the management of stocks to ensure a better yield. Research on mariculture and disease control has added to our knowledge of the biology and artificial production of these valuable species.

Mollusks are widely eaten in Britain; some species like oysters, scallops, and queens are expensive luxury foods, while cockles, mussels, and whelks are much cheaper. This paper outlines the history of Britain's most important mollusk fisheries, explains the changes which have taken place, and provides an up-to-date description of the current fisheries.

Geographical Distribution and Size

The British Isles (England, Scotland, Wales, and Northern Ireland) has an extensive coastline of about 5,000 km. In general, oysters, mussels, cockles, and clams are harvested or grown in various shallow estuaries, and the scallops are caught further out in deeper waters. Winkles are collected by hand from rocky shores, and whelks are widely distributed in many coastal areas, where they are caught in baited pots. The distribution of the main molluscan resources are shown in Figure 1 and briefly described by region below.

England and Wales

The northeast coast of England is too rocky to support any important bivalve mollusk fisheries, although scallops are caught farther out in the North Sea. Winkles are collected from the rocky shores, and whelks are present in some places and are heavily exploited.

An area of the east coast known as "The Wash" supports a major cockle and mussel fishery, and there are important whelk grounds off the Norfolk coast. Pacific oysters are also grown in this area.

Oyster beds have traditionally been important in the shallow estuaries of Essex and both native and Pacific oysters are cultivated. Large beds of cockles in the outer Thames Estuary support a valuable fishery.

The Solent, on the south coast near the Isle of Wight, is a major "native" oyster fishery, and Southampton Water has the largest natural stock of American hard clams (accidentally introduced from the United States in the early 1900's) (Utting and Spencer, 1992).

Various estuaries along the south and southwest coasts have small mussel beds, and there are an increasing number of Pacific oyster culture ventures. The River Fal estuary in Cornwall has a large native oyster fishery, but production has been hit by the disease *Bonamia.*

In the northwest of England, large cockle and mussel beds are located in Morecambe Bay and the Ribble Estuary. The Welsh coastline has commercial cockle fisheries in the Burry Inlet, and mussels and Pacific oysters are grown in the Menai Strait.

Scotland

Scottish waters, particularly on the west coast, are well suited to mollusk production. In recent years, along with the valuable fisheries for wild scallops, there has been considerable investment in mussel farming, using rafts and longlines, and an expansion in Pacific oyster production. A native oyster fishery in Loch Ryan exploits one of the few natural stocks left in Scotland.

On the east coast, the Dornoch Firth holds the Tain Mussel Fishery, which has a large wild mussel stock. Other Scottish estuaries have dense mussel beds, but the quality is poor due to overcrowding.

Mussels are also cultivated along the west coast, where numerous mussel farms produce small quantities by hanging culture. The quality of these mussels is excellent, and there is a growing demand, mainly in the United Kingdom, for Scottish farmed mussels.

The scallop, *Pecten maximus*, and the queen scallop, *Chlamys opercularis*, are both present in sufficient quantities to support important fisheries in a number of areas off Scotland.

There is growing fishing pressure on the wild scallop stocks using trawls and dredges. Attempts are being made to cultivate both species of scallops in Scotland, using modified Japanese methods for spat collection and growth. Although four or five farms are in commercial production on the west coast, the annual output is less than 200 metric tons (t), mainly queen scallops.

Northern Ireland

In recent years, the bivalve industry in this area has been dominated by one Pacific oyster culture and export business based at Strangford Lough. There is a native oyster fishery in the River Foyle and wild mussels are taken from Belfast and Carlingford Loughs.

Importance of Mollusk Fisheries

In 1994, the total production of shellfish in Britain was 111,080 t with a first-sale value of £128 million (US$192 million). This catch included crustaceans, cephalopods, and mollusks.

Table 1 shows the main mollusk species, which made up a catch of 55,795 t worth £31.7 million (US$47.5 million) in 1994. The weight represented 50% of the country's total shellfish catch but only 25% of the value.

The scallops and queens are the most valuable species landed (£23 million or US$34.5 million combined) whereas the cockle, mussel, and winkle catches are each worth around £1 million (US$1.5 million). For record purposes, the landings of mollusks during

Figure 1
General distribution of mollusks around Britain.

8 selected years between 1947 and 1994 have been tabulated in Table 2.

Landings of the different mollusk species fluctuated considerably during these 40 years, and many factors will have contributed to increases and decreases in production.

In bivalves, the level of recruitment is a major factor controlling any expansion of the fishery. The growth in artificial production using hatchery stock (e.g. Pacific oysters) will help to increase production of some species, but proper management of the stocks to control exploitation will be of vital importance in the coming years.

While the government statistics for mollusks are underestimated (probably tenfold) it is obvious that U.K. mollusk production is low compared to other western countries. The future for mollusks is considered separately for each species but, in general, we expect better market opportunities in Europe and improved production methods to help develop the U.K. mollusk industry in the 1990's.

Table 1
Landings of mollusks by British fishing vessels in 1994.[1]

Species	Weight (t)	First-sale value (£ thousands)
Clams	8	13
Cockles	22,329	3,069
Mussels	10,037	1,985
Oysters	[2]538	1,180
Periwinkles	2,264	1,554
Queens	2,977	1,788
Scallops	14,020	21,209
Whelks	3,312	894
Totals	55,795	31,692

[1] Source: HMSO Sea Fisheries Statistical Tables.
[2] Underestimated.

Oysters

The Flat Oyster

The native flat oyster, *Ostrea edulis*, has provided a long established fishery in England, Scotland, and Wales. Ample evidence from old discarded shells shows that the ancients used oysters as an important source of nutritious food. Records show that the Romans exploited Britain's natural oyster beds and even sent supplies back to Rome.

At one time oysters formed a staple part of the diet of the poorer sections of certain coastal communities. However, the onset of industrialization in the early 19th century initiated an expansion in oyster dredging, which turned it into one of Britain's largest fisheries.

According to Key (1991), stocks in the early 19th century were large and lightly fished. As industries began to expand inland and the railway systems developed, transport became easier and markets for oysters boomed. By 1824, important and valuable oyster fisheries had been established on the east coast of England in the larger estuaries in Essex and Kent.

The peak production period in the history of the fishery was in the mid-1800's. Philpots (1890) records that 700 million oysters were consumed in London in 1864, as well as many more in the provinces. So immense was the oyster industry that 120,000 men around the coasts of Britain were engaged in dredging oysters in the 1880's.

Most of the catch was taken by small sailing smacks with a few crew, who worked dredges by hand. Very quickly local stocks were worked out, and the east coast

Table 2
Quantities (t) of mollusks landed in U.K. during selected years and their value (£).[1]

Year	Quantity (t): Scallops and queens	Winkles	Oysters (native)	Whelks	Mussels	Cockles	Total value (£)
1994	17,000	2,264	528	3,312	10,347	22,329	£32,000,000
1990	14,015	1,766	161	755	6,610	19,593	£20,000,000
1985	12,617	2,294	477	1,630	5,825	7,826	£19,000,000
1983	16,543	2,765	290	1,336	5,856	5,837	£11,000,000
1975	14,060	2,761	488	3,148	6,913	16,385	£ 3,500,000
1965	550	550	250	1,700	2,850	7,050	£ 400,000
1955	1,158	330	903	2,247	3,826	7,584	
1947	3,379	362	424	1,730	5,539	8,792	

[1] Source: Sea Fisheries Statistical Tables.

boats started to explore sources of supply further afield. They worked every available oyster stock, some in deep water, around the English, Scottish, and Irish coasts; catches were sent direct by well-boat to London or exported to the Continent.

By the middle of the 19th century most oyster fisheries were becoming severely depleted and pressure was put on the government to remedy the situation. Parliamentary Select Committees were set up and, as a result of their reports, legislation was passed in 1877 to ban the sales of oysters in the summer, from 14 May to 4 August each year, to conserve the breeding stocks. This closed season is enforced to this day for *Ostrea edulis* under the Sea Fisheries (Shellfish) Act of 1967.

Provisions were also made for public fishing rights to be removed by the granting of regulated fisheries, where minimum landing sizes and other restrictions could be introduced by law. Meanwhile, the industry was seeking new supplies for a hungry market, but the prosperity of the oyster industry did not carry on into the 20th century (Orton, 1937).

French (1989), who provides an excellent account of the Essex oyster fisheries, reports that by 1902 the 500 million oysters reputedly sold in Billingsgate Fish Market, London, had dwindled to a total catch of 28 million for the entire country. Almost without exception, commentators have blamed overfishing for the decline. French, who has been an oyster grower all his life, believes that this is an over-simplification of the problem.

According to him, the decline started as the Industrial Revolution accelerated. Oysters disappeared first close to centers of industry and population as pollution increased. Imports of the American oyster or "blue points," *Crassostrea virginica*, from bays in the northeastern United States, which began in the 1870's, brought in pests and competitors such as the drill, *Urosalpinx* sp., and slipper limpet, *Crepidula*. The imports were to fill the gap in the trade during the summer months.

The first half of the 20th century therefore saw the British oyster fisheries in a rather depleted condition, striving to maintain momentum with additional burdens of pests. Spatfalls got smaller and less frequent, and cold winters and floods further reduced the stock levels.

Production figures for the period of 1920–72 (Fig. 2) show that the catch fell from 40 million oysters in 1920 to about 8 million during the 1950's. Good spatfalls in 1957–59 revived hopes for improved stock levels, but the severe winter of 1962–63 virtually destroyed the east coast beds. By the end of that decade, landings had fallen to a low of 3 million and production has not since grown.

In 1982, tests revealed that the disease *Bonamia* had been inadvertently introduced into several important English fisheries, causing large-scale mortalities. This further reduced the level of production in the 1980's.

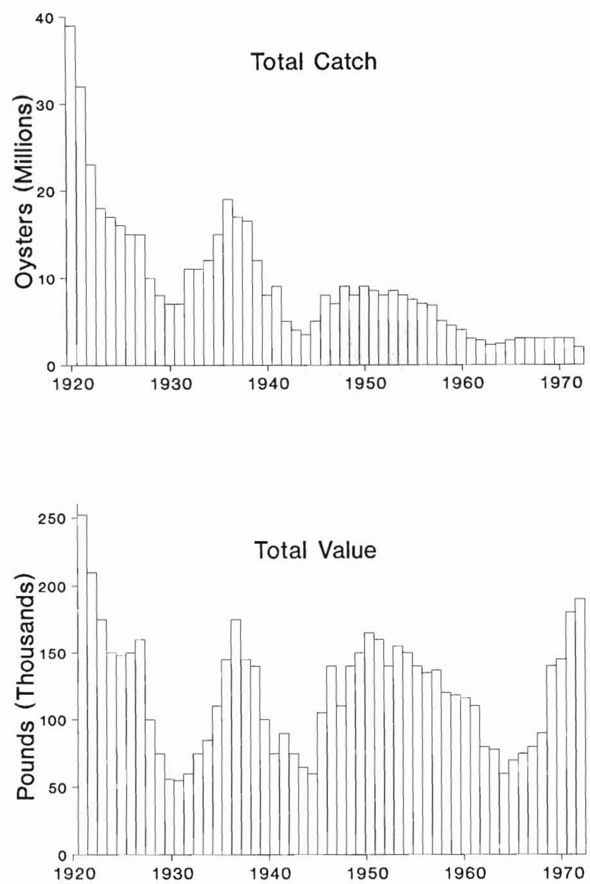

Figure 2
Landings and value of native flat oysters in England and Wales (1920–72). Source: Davidson, 1976.

Cultivation Techniques and Species

Cole (1956) and Davidson (1976) both described Britain's oyster fisheries and cultivation techniques. Four species have been cultivated during this century: the European flat oyster, *Ostrea edulis*; the Portuguese oyster, *Crassostrea angulata*; the American oyster, *Crassostrea virginica*; and more recently the Pacific or Japanese oyster, *Crassostrea gigas*.

Large imports of native oysters came from Holland and France for relaying from 1901 until 1962, when the practice diminished. Importations peaked in 1937, when it is reported that 40 million oysters were relaid on English grounds (Fig. 3).

The American and Portuguese oysters were brought in to supplement the supply of native oysters. The trade in American oysters started in about 1876 but there have been no imports from the United States since 1940, and the Portuguese trade, started in 1926, was stopped in the 1970's because of viral gill disease (Utting and Spencer, 1992).

Portuguese oysters spawned only to a very limited extent in this country, as they require a rather higher water temperature than is normally experienced even in the southern part of England. American oysters did not reproduce at all and both species could therefore be sold during the summer months, when native oysters could not be sold by law because they were spawning.

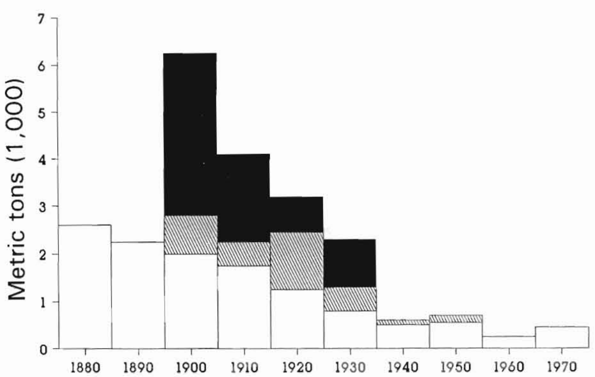

Figure 3
Landings of oysters of mixed species in the U.K. (open histograms) and imports, for direct consumption, of European flat oysters (hatched histograms) and American oysters (closed histograms). Source: Utting and Spencer, 1992.

Oyster Fishing

The European flat oyster fishery continues to use traditional techniques and gear which are often peculiar to a specific locality. Harvesting methods range from small dredges (Fig. 4) towed by rowing boats to the use of large (6-foot) dredges on 40-foot powered vessels.

Most of the oysters reaching market have been relaid from a spatting ground. A large supplier of these "brood" oysters is the Solent Oyster Fishery, on the south coast of England (Key, 1981). Its development followed the location of a large natural resource of flat oysters in 1971 and the utilization of this valuable stock to replenish beds on the east coast and for direct export to the continent up to the present day.

Cole (1956) and Orton (1937) describe the cycle of cultural operations on a traditional English oyster bed. Work begins in the spring, at the close of the marketing season (September–April inclusive) with the laying of

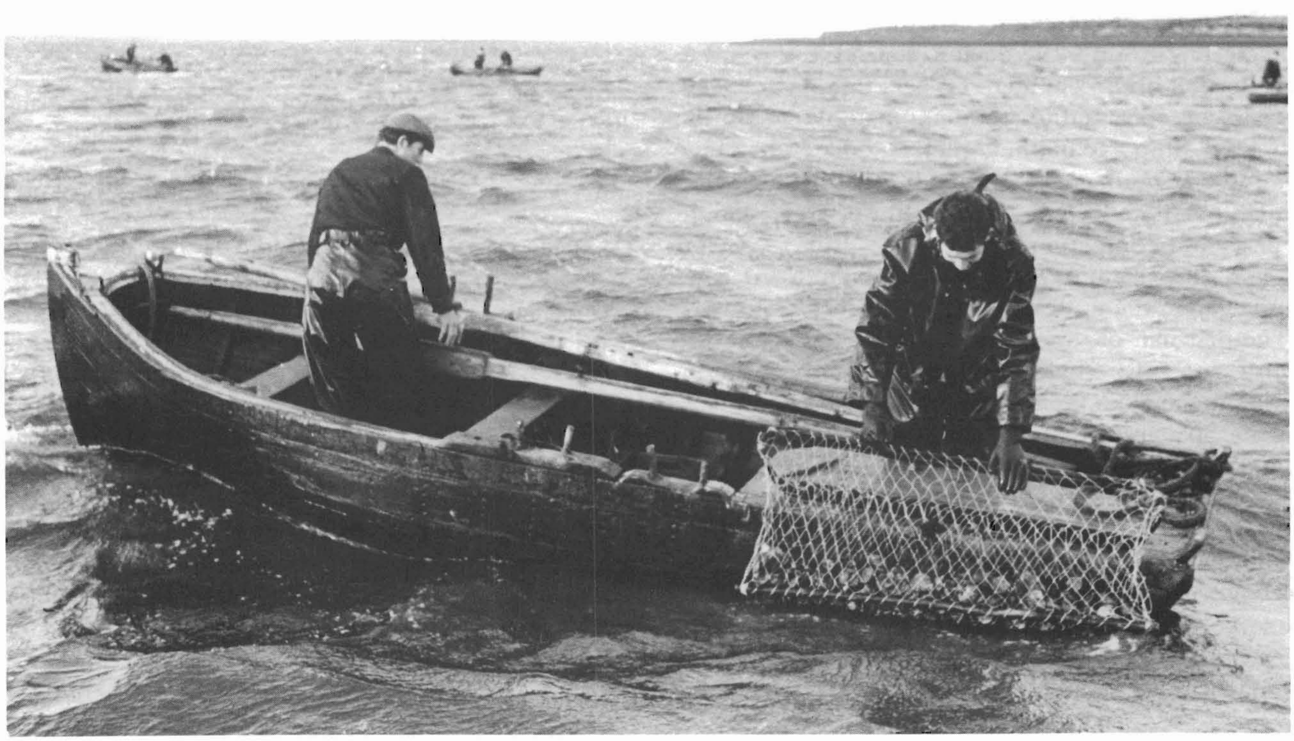

Figure 4
Dredging oysters by hand in Galway Bay, Ireland. Photograph by the author.

fresh breeding stock. During May and June attention is concentrated upon the elimination of pests, particularly the drills, *Urosalpinx* and *Ocenebra,* which breed then.

In areas which benefit from a natural spatfall, additional settling surfaces must be provided. The bottom may be dredged and harrowed to drag up fresh cultch from the mud, and the natural supply may also be supplemented by laying cockle, oyster, or mussel shell from elsewhere. At this season (June–July) oysters approaching maturity may be dredged up and relaid in localities known to give rapid growth and fattening.

June–August is usually a quiet time on most oyster fisheries, but intense activity is resumed in September, when the dredging of oysters for market begins. While dredging, the oysterman removes all pests and competitors such as shore crabs, starfish, drills, and slipper limpets. The collection of market oysters continues throughout the winter, although certain fisheries (e.g. Solent) now have a shortened fishing season to conserve the stocks. Most native oyster fishing ends in March, but the cultivation of Pacific oysters, described later, provides a source of oysters for the trade during the summer months.

Pacific Oysters

The era of massive commercial importations of oyster seed from abroad ended in the 1960's with a growing awareness of the risks involved in introducing alien pests, parasites, and diseases. The 1960's were notable for two reasons: Implementation of the Molluscan Shellfish (Control of Deposit) Order 1965, whieh controlled mollusk imports to prevent the introduction of diseases, and the development of hatchery culture seed.

Walne (1974) describes how the hatchery production of the Pacific oyster was developed at the Ministry of Agriculture, Fisheries and Food Fisheries Laboratory, Conwy, N. Wales, to a level where it could be applied on a commercial scale. Under strict quarantine conditions, *C. gigas* broodstock was brought to Conwy from the U.S. Pacific coast and induced to spawn in the hatchery. In 1979, sufficient trials had been undertaken by MAFF to assess the culture characteristics of Pacific oysters in British waters.

The research at Conwy in the 1960's, under the late Peter Walne, identified the Pacific oyster as having considerable potential to revitalize the U.K. oyster industry. The species does not spawn regularly in our cool waters, but it is robust and grows to saleable size (80-100 g) in 36 months.

Years of patient work by Walne and his team paid off. Commercial hatcheries now produce up to 100 million juvenile Pacific oysters each year. Many of these are exported abroad, but Pacific oysters are grown at some 300 sites in England, Scotland, Wales, and Northern Ireland, and this introduced oyster now makes a significant contribution to the U.K. oyster industry.

Spencer (1990) describes in detail how Pacific oyster seed should be handled and provides culture methods. Both Spencer (1990) and Drinkwater (1987) recommend tray or bag culture low down the shore (Fig. 5).

Most U.K. growers have now adopted tray or bag culture using trestles to raise the oysters off the seabed. U.K. production, based on seed supplied by a hatchery, is currently about 750 t per year and is slowly rising.

Development of the new Pacific oyster industry was hit during the 1970's and early 1980's when tributyl tin (TBT) was used as a small boat antifoulant. The presence of this toxic chemical, even at trace levels, caused severe thickening of the shells of Pacific oysters and stunted their growth.

Since July 1987, the use of TBT-based paints on small inshore vessels has been banned, and the toxic levels of TBT in most estuaries have fallen below the dangerous level. Consequently, the shell thickening which caused problems to many Pacific oyster growers has disappeared, and production is steadily increasing.

At present most growers sell their Pacific oysters to outlets such as shellfish bars, restaurants, hotels, and bars. Since they are cheaper than the native oyster, and available year-round, their popularity is increasing, and present trends indicate both an increase in production and market opportunity, including sales on the Continent.

Mussels

Mussels have been harvested from early times, either as a cheap source of food or as fish bait. Calderwood (1895) describes how many large natural mussel beds in England, Scotland, and Wales provided bait for the important line fisheries.

A Mussel Commission set up in 1889 reported that ". . . 50,000 fishermen of Scotland use mussels as their bait for part or all the year." So great was the demand for mussels for bait to supply the line fisheries that many beds were overfished and supplies were imported from Holland to boost the available stocks. The decline in this type of fishing in the 1950's ended this trade in bait.

Old records also describe how mussels were eaten by poor people, but the amounts seem to be small and there was a preference for oysters. Even so, the records of the Worshipful Company of Fishmongers show a trade in live mussels at London's Billingsgate Fish Market since the 1800's.

According to Cole (1974), mussel consumption suffered from an association with typhoid because they were often taken from sewage-polluted waters and eaten

Figure 5
Pacific oyster culture using mesh bags laid on steel trestles in Essex. Photograph by the author.

raw. This situation changed in 1920, when the first reliable cleansing technique was evolved by Dodgson (1928) at Conwy (Fig. 6). Since then, purification techniques have been further developed (Wood, 1969), mussel consumption has steadily increased, and nowadays mussels are growing in popularity as a safe seafood.

British mussel production is relatively small (Table 2), at around 10,000 t/year, and comprises less than 5% of the total European Community (EC) catch.

Large areas of tidal flats, including The Wash, Morecambe Bay, Solway and Dornoch Firths in Scotland, and other river estuaries, such as those of the Conwy in North Wales and the Teign and Taw in Devon, produce most of the wild U.K. mussel harvest. These are all areas of natural production, but the commercial development of these natural beds, however abundant they might seem, is hindered by the unpredictable nature of the stock caused by varying recruitment levels.

Mason (1972) describes in detail the cultivation of the European mussel. In Britain, there has been a gradual move from just exploiting wild beds by dredging or handpicking to mussel farming. Mason (1972) and Dare (1980) describe the bottom cultivation of mussels when small (seed) mussels are transplanted from natural beds onto "lays" in more favorable sheltered sites, where growth and survival is improved.

This technique, widely used in Holland, can be highly productive, and a properly managed ground will yield 100–125 t live weight of mussels per hectare, or 20–25 t of cooked meat, every 2 years. Mussels are suitable for sale at a minimum length of 50 mm; local bylaws in some areas prevent smaller mussels from being dredged for sale.

Mussels are also grown attached to coir and various synthetic ropes suspended from rafts and buoyed longline systems. Net tubes are also used to hold seed in this type of suspended culture (Fig. 7, 8).

Trials in western Scotland (Mason, 1969) and North Wales (Dare and Davies, 1975) showed the biological potential of floating culture even in cold temperate U.K. waters. Mussel crops reached minimum market size in $1\text{–}1^1/_2$ years and possessed high meat contents (30–35% cooked meat yields).

Since those 1970's trials, a valuable mussel industry has been developed along the west coast of Scotland, where there are many suitable deep and sheltered inlets.

In 1991, Scottish growers produced over 1,000 t of top-quality farmed mussels for which there is an in-

Figure 6
A mussel depuration plant at Conwy, N. Wales. Photograph by the author.

creasing demand. This method is more expensive and, at present, less productive than bottom culture. But it is more suitable for these Scottish waters rather than the shallow estuaries of England and Wales.

Despite improved prospects for mussels, the main problems faced by the grower are continuity of seed supplies and the effects of predation by crabs and starfish. In Britain, the shore crab, *Cancinus maenas*, causes widespread and sometimes severe losses of small mussel seed on intertidal and deep-water lays in many estuaries. Mussels below 40 mm in length are particularly vulnerable to crab predation.

Mussel beds near sewage discharge points are a particular problem, and in many areas the health authorities control or prohibit the sale of mussels from these areas unless they have been cooked or undergone an approved purification process to cleanse them (Fig. 6). In January 1993 a new EC Directive covering the hygienic production of mussels and other bivalves further reduced the risks of contaminated mussels reaching the market.

Edwards (1984) describes how many shellfish growers in Britain consider the mussel as potentially the most important mollusk in their waters. Market demand continues to improve, and exports to France and Holland are steadily increasing. Investment in new equipment such as mussel dredgers and Spanish-type raft systems will see mussel production double in the next decade.

The Common Cockle

More cockles are landed in Britain than any other mollusk (Table 1); they occur all around our coasts, living mainly between mid-tide and low-water levels. Common on sandy beaches, cockles also inhabit a wide variety of substrates ranging from soft mud to gravel.

Cockles have been exploited by generations of coastal inhabitants. But nowadays, the traditional hand-raking methods of harvesting have been replaced by hydraulic dredges and there is a huge demand for this tasty shell-

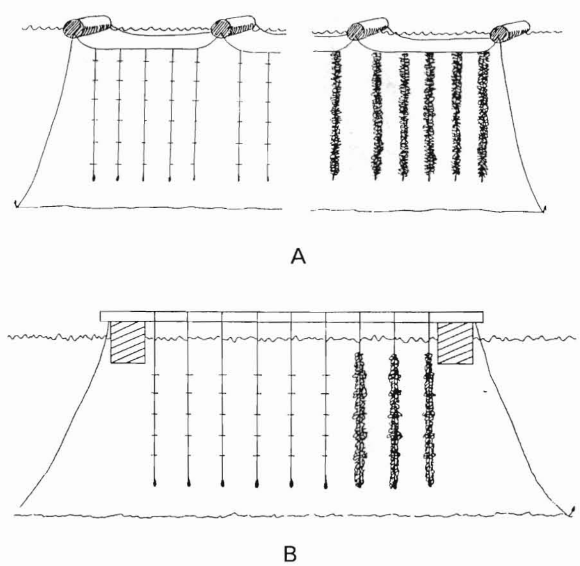

Figure 7
Types of cultivation: A) longlines, B) raft (adapted from Drinkwater, 1987).

Figure 8
Mussel farming using hanging rope culture in the west of Scotland. Photograph by the author.

fish. The main cockle beds in Britain are situated in the outer Thames Estuary, The Wash, the Dee estuary, Solway Firth in Scotland, and the Burry Inlet in South Wales.

Cockle landings have fluctuated considerably during the past 50 years; between 1930 and 1960 they oscillated around 7,500 t live weight, but have increased threefold today because of improved harvesting methods and better markets. Landings during 1960–90 demonstrated the variability of the fishery which relies on natural recruitment. Landings were fairly high in the 1960's, but the severe winter of 1962–63 wiped out much of the British stocks and catches fell. There was, however, an exceptionally good spatfall in the summer of 1963, and landings increased until the present day when between 30,000–40,000 t of cockles are landed annually.

Franklin et al. (1980) describe the cockle fisheries of England and Wales and the regulations which control them. Edwards (1992) describes the growing demand for cockle meats in Holland and Spain and how this overseas market has provided a "bonanza" for U.K. producers.

Nearly all the cockles sold in the United Kingdom are heat-processed and then sold freshly cooked or preserved in some way (IQF or vinegar/brine). Heat treatment, by boiling or steaming, cooks the meats and allows easy separation from the shells. Nowadays, there are strict cooking guidelines, and all processing factories must be approved by the public health authorities.

Particular care must be taken with cockles harvested from estuaries where the beds may be polluted by sewage. Health authorities now insist that sufficient heat treatment be provided to raise the core temperature of the cockle meat to 90°C for 90 seconds. At this level of cooking, all pathogenic bacteria and viruses are destroyed and cockles now have a much improved hygiene record.

Harvest methods vary around the country. In the Burry Inlet, South Wales, regulations restrict the use of mechanical harvesting methods and the licensed gatherers used only horses and carts for transportation until the late 1970's. Nowadays, tractors can be used but the cockles are still hand-raked out of the sand into piles, which are then sieved to allow the small cockles to return to the beds (Fig. 9). The commercial-sized cockles are then put into sacks and loaded onto the carts or tractors for transport to boiling sheds for washing and cooking.

In the Thames Estuary, The Wash and the Solway Firth, Scotland, boats fitted with modern hydraulic suction dredges exploit the stocks (Fig. 10). These dredges, developed in the 1960's, continuously remove cockles from the seabed by simply pumping seawater, sand, and cockles all up onto the deck of the vessel for sieving and packing the cockles. Catch rates can reach 2–3 t/hour, but there is no evidence yet that beds are destroyed by this efficient method.

For example, these dredges have been used in the Thames Estuary since 1971, and there is no evidence that the beds have been over-exploited with the present level of effort (7–12 boats). Even so, many cockle beds in Britain are potentially under threat from heavy fishing due to the high demand for this bivalve.

Sea Fisheries Committees, which manage the cockle fisheries in England and Wales, have local regulations

Figure 9
Hand raking for cockles in Wales. Photograph by the author.

Figure 10
A cockle dredger fitted with hydraulic suction gear. Photograph by the author.

such as restrictions on the kind of fishing gear used, a minimum landing size, and quotas. Arrangements are now in hand to restrict the level of fishing effort, especially for large hydraulic cockle dredgers.

Future prospects for the U.K. cockle industry depend both on supply and demand. There are fears that catches in many fisheries are unlikely to be sustainable at recent levels unless recruitment improves. In the meantime, even small beds of cockles are being exploited to meet the current high demand.

Scallops and Queens

Exploitation of the scallop *Pecten maximus* and its smaller cousin the "queen" forms an important fishery with landings now reaching 17,000 t (Fig. 11). Britain has had important scallop fisheries for a number of years. Mason (1985) writes that fishing for scallops was recorded in England and Ireland as early as the 16th century, but it did not spread to Scotland, where scallops were often called "clams" until the early 1930's. The big increase in fishing did not come until the early 1960's and, prior to that, most of the scallops were sold alive at Billingsgate Fish Market, London.

Until World War II, the smaller queen scallop was used in Scotland as cod and haddock bait by line fishermen. With the decline of line fishing after the World War II, there was no further need for the queens, and the fishery stopped. However, in about 1967 developments in processing equipment made it possible to handle and prepare queens more easily and economically. At about the same time a market was found for them in the United States, where the meats filled a

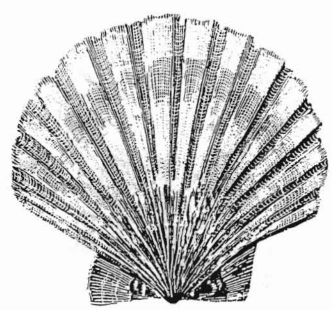

Figure 11
Scallops landed in the U.K.: A) king scallop, *Pecten maximus*, 100 mm width; B) queen scallop, *Chlamys operularis*, 50 mm width.

similar culinary place to the local "bay scallop," *Argopecten irradians*. Since the queen fishery developed in the early 1970's, many boats have alternated between the two species, although the larger scallop fetches a better price.

The U.K. scallop fisheries are very valuable, and in 1994 the catch of both species was recorded as 17,000 t worth £23 million (US$35 million). Of that, Scottish fishermen alone produced 11,400 t (67%).

Mason (1983) describes the development of the Scottish scallop fishery; the west coast is the main fishing area, but new beds have recently (1992) been exploited in the Moray Firth, on the eastern side of Scotland, and around Orkney and Shetland.

Despite 20 years of exploitation, the yield from Scotland's scallop resources remains high. Experience has shown that as the catch rate on one bed declines, fishermen tend to move to other scallop beds or change to an alternative fishery (e.g. trawling for fish). In England and Wales, the main fishing areas are in the English Channel and in the Irish Sea, but catches have fallen recently because of heavy fishing and poor recruitment.

Fishing Methods

Scallops are caught in heavy dredges towed over the seabed. On some inshore grounds the scallop populations are exploited by skin divers, but many beds are too deep for this method.

The history of scallop dredging is of interest. The traditional scallop gear is the dredge, fitted with a toothed bar. In the late 1950's and early 1960's, the boats fished from two to four dredges, 4 feet in width. In the early 1960's, bigger boats came into the fishery and used larger 6-foot dredges, towed by separate warps. Later the dredges became standardized at the 4-foot width, and they were fixed to a towing bar with 2 to 5 dredges attached (Fig. 12). The latest development was the spring-loaded toothed bar which allows the gear to pass over various hazards on the seabed without hanging up. Beam trawls are also used to take queen scallops. Indeed, since they can swim quite actively, queens can avoid the toothed dredge, which is more effective for the slower scallop.

Markets

Scallops have long been considered a luxury shellfish. Demand varies, but scallops generally find ready markets at home and abroad. At present, scallop markets are very good; there is a growing U.K. demand, but most of the catch is still exported to the continent, mainly to France.

Supplies are exported either fresh (in the shell or shucked) or frozen. Traditionally, scallops are sold with the gonads (roe-on) as this adds to the appearance of

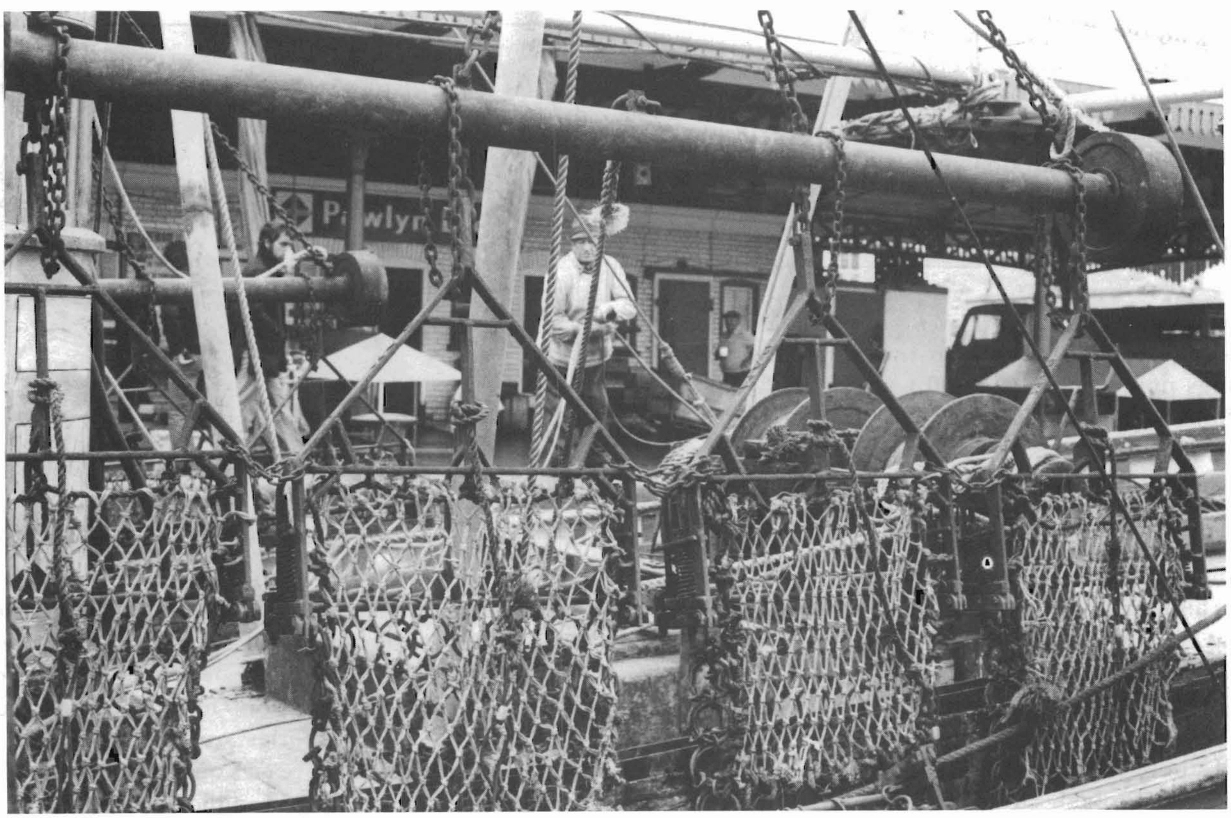

Figure 12
Scallop dredges fitted to a towing bar. Photograph by the author.

the product. However, in the U.S. trade only the white adductor muscle was exported. A growing number of countries now recognize scallops as a high-value seafood, and the 1990's are expected to see the strong demand for scallop meat continue to rise. This increased demand will encourage fishermen to search for new beds, and there is a growing interest in farming scallops using methods developed in Japan.

Mason (1983) describes the development of scallop culture in Scotland, where both species are farmed, using collectors made of monofilament netting in mesh bags laid out along the coast to collect the "spat" during the times of natural spatfall. The scallops are then grown in lantern nets (Fig. 13). This culture system, now used on the west coast of Scotland, allows growers to obtain a cheap supply of natural spat collected from the sea, though only small quantities of farmed scallops have so far been marketed.

In Scottish waters, scallops reach a commercial size of 100 mm (at 20 meats/pound, roe-on) in 3–4 years. Queens reach a saleable size of 60 mm in $2^1/_2$ years and give a yield of 60–70 meats/pound. There are 26 registered scallop and queen farms in Scotland, and production is about 80 t.

Figure 13
Scallops are grown to salable sizes in lantern nets. Photograph by the author.

According to the Food and Agricultural Organization of the United Nations, the international demand for scallops will come from the United States and France, but new markets are expected to develop in Spain, Italy, and Portugal where seafoods are popular. Scallops are seen as an easy-to-use product which fits well into the requirements of the seafood processing industry and modern consumption habits. The future for the U.K. scallop industry in the 1990's looks bright.

Other Species

The whelk and the periwinkle are gastropods which are commercially exploited in parts of Britain. These "sea snails" have been eaten as a cheap source of food for centuries but, in recent years, valuable export industries have developed around them (Table 1).

The common whelk, called the "buckie" in Scotland, is a carnivorous animal which is easily caught in pots baited with dead fish. Various types of pots are used around our coasts. Types with an iron frame were favored because of their weight, but concrete-based plastic pots are now common. Whelks can be caught year-round, but catches do decline in hot summers, when the warming of the water tends to make this animal sluggish, and at extremely low temperatures.

The traditional market for whelks is at the seaside holiday centers, where they are sold at shellfish bars. Since whelk meat can be tough and rather indigestible, this seafood is not favored by the modern gourmet, and home sales have declined. In 1990 the fishery was boosted by large exports of the extracted meats to Korea and Japan. How long this trade will last is not known but, in 1996, supplies were still being sent frozen to the Far East in 20 t container loads.

In Scotland, and to a much lesser extent in England and Wales, the collection of "winkles" is an important part of the local economy. Production data in the Government's fisheries statistics (Table 2) are completely underestimated because winkle pickers include school children, the unemployed, and the retired, and their catches are mainly unrecorded. Furthermore, 95% of the catch is exported alive to the continent, where this small gastropod is considered a delicacy.

Clams are not an important shellfish in Britain. The native clam or "palourde," *Tapes decussatus*, is highly valued in Europe, but natural U.K. stocks are small. The Manila clam is a more recent introduction to Britain, with broodstock being imported by MAFF from the U.S. State of Washington in 1980. Trials by staff at the

Fisheries Laboratory, Conwy, N. Wales, have proved the Manila clam to be a hardy, fast-growing species, with substantial potential for commercial production (Utting, 1987).

Similar in appearance to the native species and easy to rear in the hatchery, Manila clams are now being cultivated in Britain, but production is still below 100 t. Spencer et al. (1991) describe the culture techniques of Manila clams using trays or plots on the shore, protected with netting.

The American hard-shelled clam, *Mercenaria mercenaria*, was brought to England in the early 1900's and has become established as a self-sustaining population on the south coast of England, in Southampton Water. Whether its introduction was deliberate or accidental is subject to speculation. It may have been brought over by American servicemen during World War I or in ballast in sailing ships from New York City, or it may have been discarded from transatlantic liners sailing to Southampton (Utting and Spencer, 1992).

These clams have been a valuable resource for local fishermen who harvested them by hand before 1970 but later dredged the stock. The fishery is now in decline, due to the lack of any substantial spatfall, after the closure of a nearby power station, which helped to raise water temperatures in the confines of Southampton Water.

Future Prospects

Turning first to production, it must be stressed that most wild U.K. stocks of native oysters, mussels, scallops, and queens have been exploited for decades and most populations are already being exploited at varying levels. The cultivation of Pacific oysters and clams is still a small part of our industry, but there are signs of slow growth. There are still opportunities to increase home demand; the need is to persuade existing customers to eat more mollusks and also to persuade nonconsumers to start eating these shellfish.

If supplies can be increased by better management of the wild stocks and by increased farming, there are opportunities for British producers to export to the continent, where mollusks are widely eaten. The U.K.'s strengthening links with the EC and the formation of a "Single Market" in 1993 should help develop markets, especially in France and Spain.

However, the British industry faces many problems in taking advantage of these opportunities. Tougher EC health regulations will raise standards, but some small growers may have inadequate capital to meet the upgraded depuration and hygiene standards. The U.K. shellfish industry faces increasing opposition from the environmental lobby and the designation of British estuaries as areas for nature conservation may result in shellfish developments being hindered. Conflict with other water users, such as industrial and recreational interests, is also affecting investment and confidence in the future.

There is also a need to promote our shellfish. The Sea Fish Industry Authority is the organization which develops and helps to promote U.K. fisheries. Efforts to raise product awareness of U.K. mollusks, both fresh and frozen, must be increased. Quality is of particular importance, but there are still opportunities which could lead to exciting and profitable development of Britain's mollusk industry.

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The Belgian Mollusk Fisheries*

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ABSTRACT

Bivalves and gastropods landed in Belgium are taken as a by-catch of fisheries targeting finfish or crustaceans, and the nation has never had specialized molluscan fisheries. Species landed consist mainly of whelk, *Buccinum undatum*; and scallops, *Pecten maximus* and *Chlamys* spp. Long-term trends in the landings of mollusks are closely related to long-term changes in fleet and vessel size, gear types used, fishing grounds and target species, and demand on the local market. In the 1950's, the annual landings of whelk fluctuated between 80 and 200 t, while those of scallop were insubstantial. Since then, the landings gradually rose to record figures of 678 t for whelk and 762 t for scallop in the mid-1970's. Most recently, there has, however, been a substantial drop in the landings of both species. Provisional figures for 1991 and 1992 revealed an almost 50% decrease in landings for whelk, and 80% decrease for scallop. Documented history on mollusk trade and consumption in the area nowadays called Belgium goes back to the early days of the Roman occupation. A regional seafood specialty in Belgium is "moules frites" (blue mussels, steam boiled with a mixture of vegetables, and served with French fries). In 1990, over 30,000 t of mussels were consumed, all of which were imported, mostly from the Netherlands. Whelk is eaten locally, but other mollusk species, such as scallops, venerids, and cardiids, were not eaten to any extent until recent decades. Mollusks, as a whole, contribute about one-fifth to the nation's per capita consumption of finfish and shellfish.

Introduction

When, around 55 B.C., the Roman emperor Gaius Julius Caesar conquered the lands west of the lower Rhine River, he met such a fierce resistance that in his written comments he called the Belgians the bravest of all Gauls: "Horum omnium fortissimi sunt Belgae, ..." Since then, the Roman empire has faded away, and so has the Belgians' fame. Nowadays Belgians have the reputation, not so much of being the bravest, but certainly of being the most burgundian of all Germanic peoples—a race that does not despise a delicate meal and a hearty drink. In gastronomic terms this is translated into a broad choice of local dishes and beverages.

When it comes to mollusks, however, the inventory of regional specialties is limited to just one: "Moules frites" (blue mussels, *Mytilus edulis*, steam-boiled with a mixture of vegetables and served with French fries). Its popularity can easily be measured from the quantities of mussels consumed: In 1990 these amounted to over 30,000 metric tons (t) (1.1 million bushels), by a total population of just under 10 million people. Most unfortunately for the local fisheries, however, all mussels are imported.

This roughly sets the tone for the Belgian mollusk fisheries; Belgium never had any specialized molluscan fisheries, and for various reasons probably none will ever develop. Bivalves and gastropods landed in Belgium are taken as a by-catch of fisheries targeting finfish or crustaceans, and the number of species marketed is small—mostly whelk, *Buccinum undatum*, and "scallop," the common denominator for a mixture of mainly great scallop, *Pecten maximus*, with much smaller quantities of queen scallop, *Chlamys* spp.

For many years research priorities in the Belgian fisheries have been on much more economically important species or species groups: Herring (in the years immediately before and after World War II), gadoids, flatfishes, shrimp, and Norway lobster, *Nephrops norvegicus*. As a matter of fact, this is the first attempt ever made to comprehensively review the Belgian mollusk "fisheries." For practical reasons, the review is limited to the period between 1950 and 1990. All fishing areas mentioned in the text are shown in Figure 1.

* This study was subsidized by the Institute for Scientific Research in Industry and Agriculture (ISRIA), Brussels, Belgium.

Development of the Mollusk Fisheries

The 1950's

In the early 1950's the Belgian trawler fleet comprised about 460 vessels, with an overall fishing capacity of roughly 60,000 HP (Fig. 2, 3). The vast majority (about 290 vessels or almost two-thirds of the fleet) were small cutters and shrimp trawlers of <50 GRT, with engines of <120 HP. The fleet also counted about 150 mid-class motor trawlers (50–150 GRT and 120–350 HP) and a small number of large motor and steam trawlers (>150

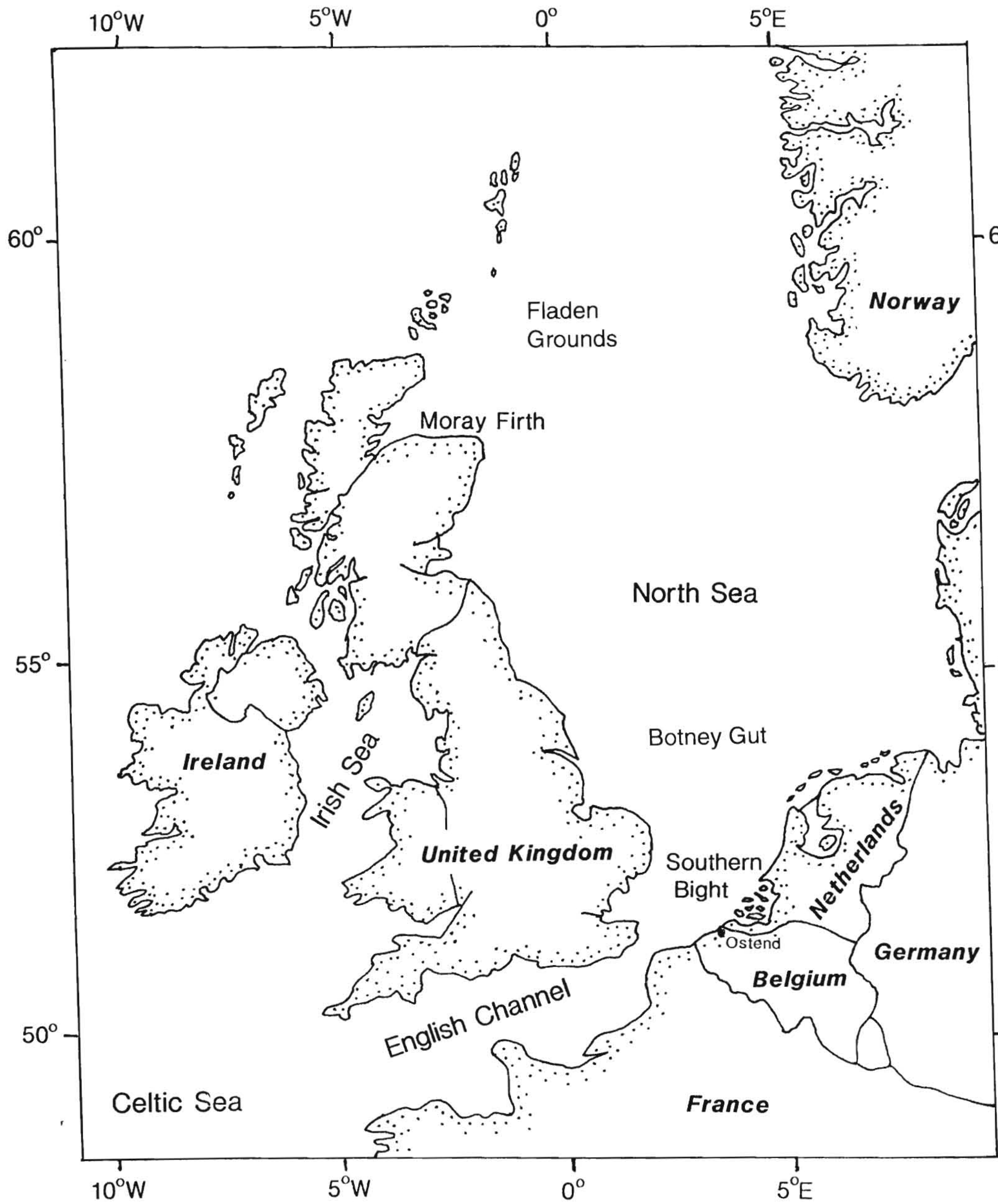

Figure 1
Major fishing grounds of the Belgian trawler fleet in the North Sea and adjacent waters.

GRT and >350 HP). The latter included some older vessels, built in British shipyards in the mid–1920's.

Shrimp trawlers, cutters, and the smaller motor trawlers were concentrated mainly in the coastal waters, the Southern Bight, and the easternmost part of the English Channel, where they fished for brown shrimp, *Crangon crangon*; gadoids (cod, *Gadus morhua;* and whiting, *Merlangius merlangus*); flatfish (especially plaice, *Pleuronectes platessa*; and sole, *Solea solea*), various species of rays, *Raja* spp.; herring, *Clupea harengus*; and sprat, *Sprattus sprattus* (Fig. 4, 5).

Most mid-class and some of the larger trawlers fished in the northern North Sea (particularly in the Moray Firth and on the Fladen Grounds) and the central and the southern North Sea. Their landings consisted mainly of gadoids (haddock, *Melanogrammus aeglefinus*; cod; and whiting), flatfish (plaice and sole) and, locally and seasonally, herring (Fig. 4, 5).

The largest vessels successfully fished for gadoids (haddock; cod; saithe, *Pollachius virens*; and whiting), ling, *Molva* spp.; and redfish, *Sebastes* spp.; on the southern and western coast of Iceland. In 1950, their landings accounted for about one-fifth of the Belgian finfish and shellfish production; 5 years later they scored the highest ever landings of 20,850 t, just under one-third of all finfish and shellfish landed in Belgium (Fig. 4).

In the early 1950's, the fisheries on the so-called western grounds (English Channel, Celtic Sea, and Irish Sea) were not particularly important. Together they yielded between 3,000 and 5,500 t of finfish and shellfish annually, or <10% of the Belgian landings (Fig. 4).

In the immediate post-war period, otter trawling was the most popular fishing method: Demersal for roundfish, flatfish, and shrimp; pelagic or semipelagic for herring and sprat. Beam trawling, which proved to be much more efficient to catch shrimp and flatfish, was introduced in the shrimp fishery in the early 1950's (Desnerck and Desnerck, 1976), but it took almost 10 years before this technique was largely adopted by the flatfish-directed trawlers.

Otter trawling is not the most efficient way to catch strictly benthic organisms, such as whelk or scallop. Thus, the whelk and scallop landings remained small to insubstantial throughout the 1950's. Annual landings of whelk fluctuated between 80 and 200 t, with the highest figures being recorded in the early 1950's (Fig. 6). Great scallop and queen scallop were only considered as a

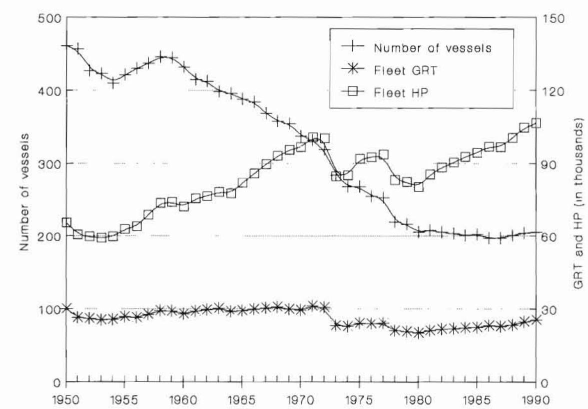

Figure 3
Number of vessels, overall gross tonnage (GRT in thousands), and nominal fishing power (1,000 HP) of the Belgian trawler fleet, 1950–90.

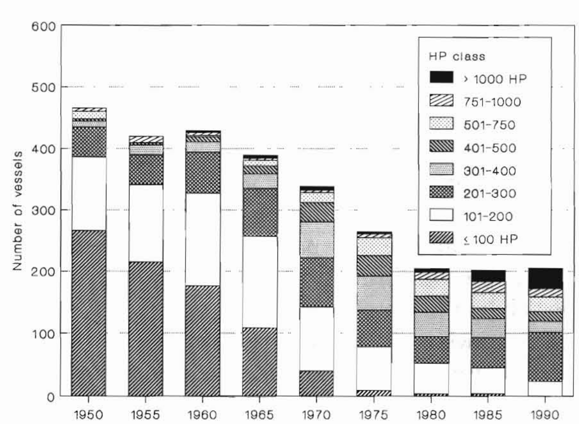

Figure 2
Numbers of vessels in the Belgian trawler fleet by horsepower class, 1950–90.

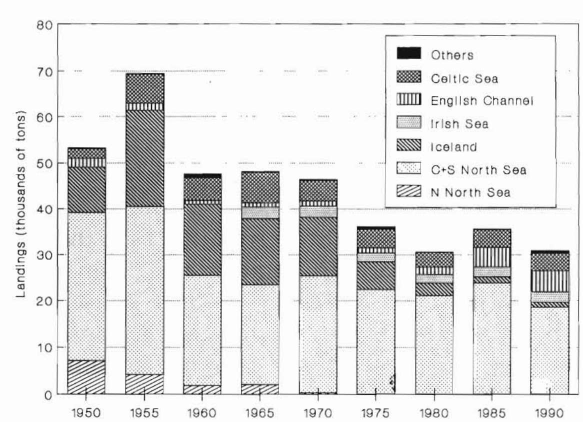

Figure 4
Quantities of finfish and shellfish landed by the Belgian trawler fleet (thousands of metric tons) by ICES Subarea, 1950–90.

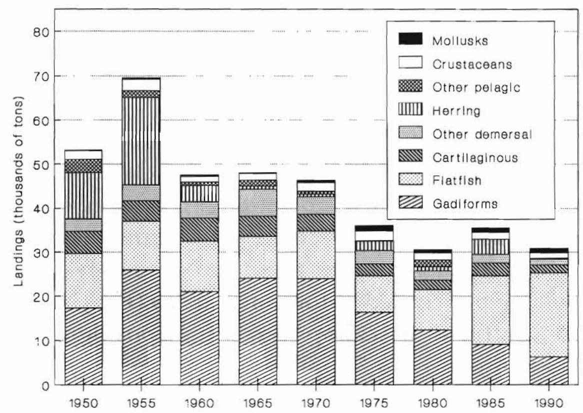

Figure 5
Quantities of finfish and shellfish landed by the Belgian trawler fleet (thousands of metric tons) by species or species group, 1950–90.

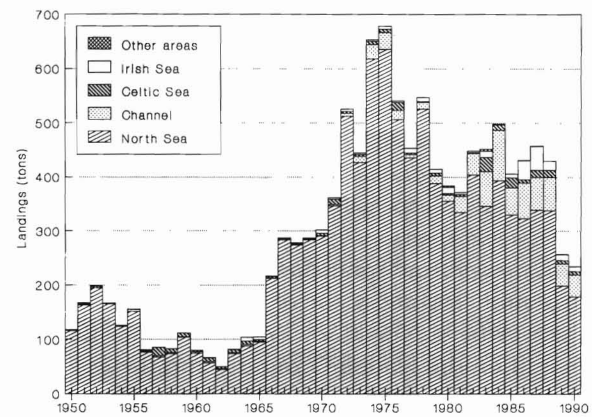

Figure 6
Belgian landings of whelk, *Buccinum undatum*, all fishing gears combined, by ICES Subarea, 1950–90.

separate item in the official landings statistics from 1972 onward. Until then they were included under the heading "Other shellfish," i.e., all shellfish except brown shrimp; Norway lobster; lobster, *Homarus gammarus*; brown crab; *Cancer pagurus*; cephalopods; and whelk. Judging from the quantities of "Other shellfish" landed in the 1950's (<25 t and most often even <5 t/year), the landings of great scallop and queen scallop must have been extremely low at that time.

During the 1950's only minor changes occurred in terms of fleet composition and fishing capacity; fleet size slightly decreased to 432 vessels in 1960; average gross tonnage remained fairly constant; and average engine power rose slightly from 142 HP in 1950 to 167 HP in 1960. Despite the decrease in fleet size, the overall fishing capacity increased by 20% from about 60,000 HP in the early 1950's to just over 72,000 HP in 1960 (Fig. 3).

The changes in terms of catch composition, on the other hand, were much more pronounced. The distant fishery in the Icelandic waters peaked in 1955, then slowly declined to about 16,000 t in the early 1960's (Fig. 4). Overfishing of the herring stocks in the North Sea resulted in a sharp drop in landings, from 19,800 t in 1955 to merely 3,700 t in 1960. As a consequence, gadiforms became by far the most important species group, representing >40% of the Belgian finfish and shellfish landings (Fig. 5).

Early 1960's to the Mid–1970's

In the early 1960's, several trends began to develop within the Belgian fishing industry which would have a major impact on whelk and scallop landings. Throughout the 1960's, many small cutters and shrimp trawlers were decommissioned (Fig. 2). Simultaneously, new and much larger vessels entered the fleet (albeit in smaller numbers), while the engines in many existing vessels were replaced by more powerful ones. Up to the early 1970's, the nominal decrease in fleet size was largely matched by the net increase in average engine power. As a result, total fishing capacity gradually rose from about 72,000 HP in 1960 to just over 100,000 HP in the early 1970's, after which it slightly decreased again to about 92,000 HP in 1975 (Fig. 3).

In the 1960's the Belgian finfish-directed trawler fleet also started to switch from otter trawling to beam trawling. The beam trawl had already been introduced in the shrimp fishery in the early 1950's (see previous section) and, since then, it had become increasingly popular. Beam trawling for flatfish started in the mid–1960's, and because of its obvious merits of yielding much higher catch rates, it quickly superseded otter trawling. Many vessels were adapted or even reconstructed to allow beam trawling. Most of the newly built units were from the very beginning conceived as beam trawlers, or as multifunctional trawlers which could use either a beam or an otter trawl.

Beam trawls owe their effectiveness to the much heavier groundrope and the fact that they can be easily rigged with so-called tickler chains. Tickler chains sweep the seabed in front of the groundrope and raise flatfish from the seabed into the trawl's mouth. Heavy groundropes and tickler chains also contribute to increase catches of epibenthic animals, such as large gastropods, scallops, and starfish.

Figure 7
Nephrops-directed otter trawler (27 m length over all, 98 GRT, 375 HP) fishing in the Botney Gut-Silver Pit area, central North Sea. Photograph by E. Coucke.

Later on, the development of chain mats and groundropes with wooden or rubber "bobbins," enabled the beam trawlers to fish for flatfish even on rough grounds with scattered boulders and stones, which were not accessible to otter trawlers.

The overall increase in nominal fishing power throughout the 1960's, combined with the introduction of the much more efficient beam trawl in the mid–1960's, resulted in a considerable increase in effective fishing capacity of the Belgian trawler fleet, especially with respect to bentho-demersal finfish and shellfish. This had an immediate effect on the whelk landings, which quickly rose from about 100 t in 1965 to a record of 678 t in 1975. Over 90% of these were caught in the North Sea (Fig. 6). This is not surprising because at that time most of the flatfish-directed effort was confined to the North Sea. Precise data on the areal distribution of the fishing effort are not available for this particular period but, judging from the proportions of plaice and sole taken (the prime target species of the beam trawlers), it can be assumed that some 65–90% of the beam trawl effort must have been concentrated in the North Sea.

Another feature which undoubtedly contributed to the increase in the whelk landings was the expansion of the *Nephrops* (Norway lobster) fishery in the central North Sea (particularly in the Botney Gut-Silver Pit area) from the late 1960's onward (Fig. 7).

Throughout the 1950's and most of the 1960's, the larger part (60–90%) of the *Nephrops* landed by Belgian trawlers was taken in Icelandic waters. In the late 1960's and early 1970's, however, the landings of Icelandic *Nephrops* fell sharply, and in 1974 they came to a definite end. The latter was an immediate consequence of the September 1972 agreement between Iceland and Belgium which laid down the conditions under which Belgian trawlers were allowed to fish in the Icelandic EEZ. This agreement included, amongst others, an explicit ban on *Nephrops* trawling.

The gap in the market, created by the "loss" of the Icelandic *Nephrops* grounds, was quickly filled by the expansion of the *Nephrops*-directed otter trawl fishery in the central North Sea. *Nephrops* landings from this area almost doubled from the late 1960's to the late 1970's, from 295 t in 1968 to 575 t in 1978.

In the 1980's (the only period for which accurate landings data by statistical rectangle, gear type, and vessel class are available) the *Nephrops*-directed otter trawlers landed between 35 and 65 t of whelk annually, i.e., 10–20% of all whelk caught in the North Sea by Belgian trawlers. Similar vessel class or gear statistics are not available for the 1960's or the 1970's, but it seems likely that the increase in the *Nephrops*-directed effort in the late 1960's and in the 1970's contributed to the increase in landings of whelk from the North Sea as well.

Scallop was not dragged along by the same stream of events which pushed up the whelk landings from the mid–1960's onwards. For several reasons it took almost another decade before the scallop landings started to rise (Fig. 8).

First of all, the offshore fishing grounds in the North Sea never have been extremely rich in scallops. According to ICES statistics, the North Sea as a whole never yielded >10% of the European scallop landings, most of which were taken in inshore waters on the British east coast. This explains, at least in part, why the Belgian scallop landings remained at a low level throughout the 1960's and the early 1970's. At that time, most of the Belgian beam trawl effort was concentrated on the more or less offshore fishing grounds in the North Sea, which are even poorer in scallop than the coastal waters.

However, judging from the quantities of scallop landed from the North Sea in the 1980's, it is almost certain that the quantities caught in the 1960's and early 1970's must have been large, as compared with the few tons actually landed. Discarding must have been substantial, and this was closely related to the small sales potential for scallop at that time. Unlike whelk, scallop had little or no "culinary tradition" in Belgium. Cooked or steam-boiled whelk was a well-known dish, especially to the coastal population, but for some reason scallop was not widely appreciated. This started to change in the early 1970's. The revival of tourism and gastronomy, both induced by the economic boom of the "Golden Sixties," helped to familiarize the Belgian consumer with more "exotic" seafoods, such as scallop, squid, and cuttlefish. A market was established, and from the mid–1970's onwards, the national demand for scallop quickly rose.

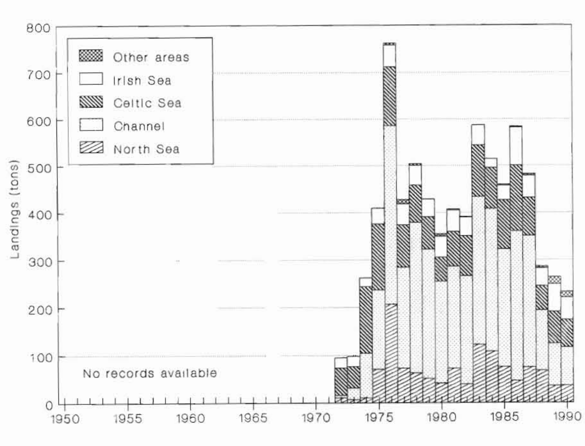

Figure 8
Belgian landings of scallops, *Pecten maximus* and *Chlamys* spp., all fishing gears combined, by ICES Subarea, 1950–90.

Mid-1970's to the Mid-1980's

In the late 1970's and throughout the 1980's, modernization of the Belgian trawler fleet continued (Fig. 2, 3). Fleet size decreased further, from 268 vessels in 1975 to 205 in 1980, then roughly stabilized. Between 1975 and 1985 the average gross tonnage rose from 90 to 110 GRT, and the average engine power from 343 to 468 HP. These trends continued during the late 1980's, raising the average gross tonnage to 124 GRT in 1990, and the average engine power to 520 HP. Over the same period the overall fishing capacity of the fleet first decreased from about 92,000 HP in 1975 to just below 80,500 HP in 1980, then steadily increased again to its present level of about 107,000 HP (Fig. 3).

Changes in landings composition were most striking with regard to both areas fished and species landed. By the end of the 1960's, the herring fisheries had completely collapsed and, except for a short upsurge in the mid-1970's and another one in the mid-1980's, annual landings hardly exceeded 1,000 t or even 500 t. Because of the "facing out" agreement with Iceland, the landings from that area (mainly gadoids and redfish) fell off rapidly from about 12,500 t in the early 1970's to <1,500 t in the mid-1980's. On top of that, several important gadoid stocks, especially in the North Sea, started to suffer from overexploitation, causing an extra drop in the gadoid landings (Fig. 4, 5).

Consequently, the Belgian trawler fleet was increasingly geared to flatfish (Fig. 9, 10). In 1982, flatfish became the most important species group in the landings. By 1990, their part in the Belgian finfish and shellfish production had reached record levels of 61.5% and almost 70%, respectively, of quantities landed and gross return to the fishermen (Fig. 5 and 11).

The search for plaice and sole led to a further overall increase in beam trawl effort and to a further diversion of effort to the western fishing grounds (English Channel, Celtic Sea, Irish Sea, and Bay of Biscay). Sole-directed beam trawl effort (which may be considered as a fairly reliable index of the overall fishing effort toward flatfish) rose sharply from the mid-1970's to the

Figure 9
Flatfish-directed beam trawler (30 m length over all, 182 GRT, 900 HP) of the type currently fishing in the North Sea and on the western grounds. Photograph by R. Fonteyne.

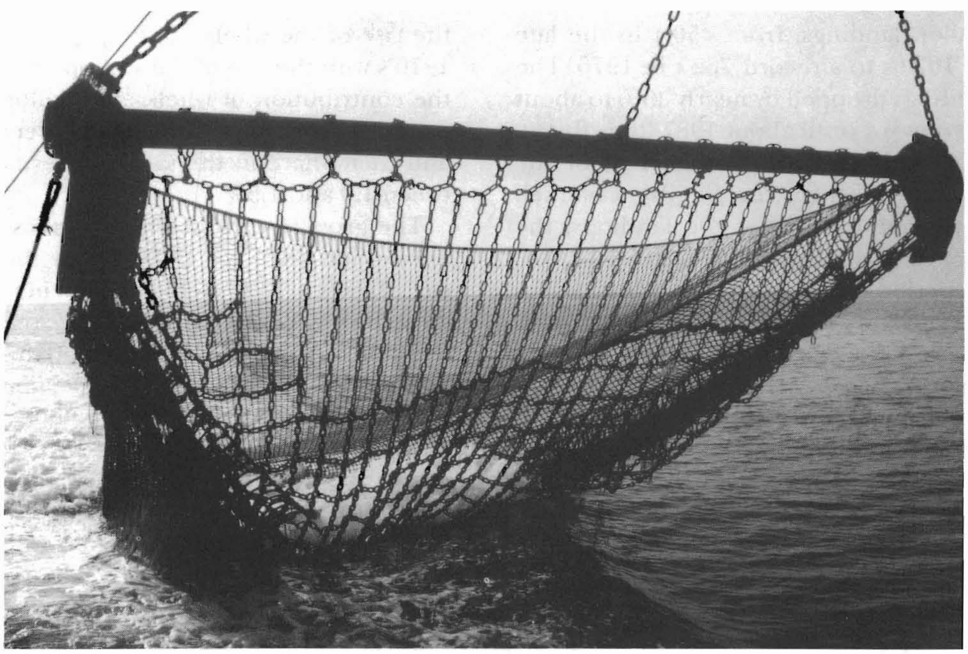

Figure 10
Beam trawl with chain mats, used to fish for flatfish on rough grounds. Photograph by R. Fonteyne.

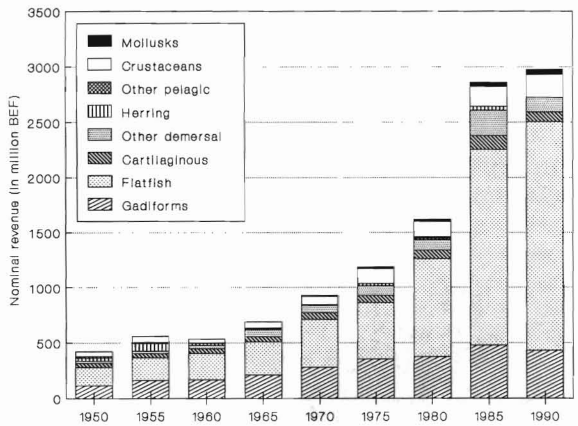

Figure 11
Gross return of the Belgian finfish and shellfish landings by species or species group, 1950–90.

early-1980's in all western areas. Trends varied from one area to another, from a roughly 50% increase in the Celtic Sea and the Irish Sea, to a steep fivefold increase in the English Channel.

The overall increase in flatfish-directed fishing effort in areas with high scallop densities (such as the English Channel and, to a lesser extent, the Celtic Sea and the Irish Sea), together with the increasing demand for scallop on the national market, brought about a real boom in the scallop landings, from <50 t in the late 1960's and early 1970's to a record 762 t in 1976. The next year, the landings dropped by nearly 45% to about 430 t. From then onward until about 1987, they fluctuated between 350 and 600 t. More than half of the scallop landings were taken in the English Channel. The Celtic Sea yielded 15–25% of the landings, the North Sea 10–20%, and the Irish Sea 5–15% (Fig. 8).

Over the same period, whelk landings were at a similar level, fluctuating between 350 and 500 t. Until 1982, >90% of these were landed from the North Sea. Together with scallop, however, the landings of whelk from the western grounds (especially from the English Channel) rose sharply during the middle and late 1970's, and by 1983 their part in the Belgian whelk landings had reached 20–25% (Fig. 6).

The Late 1980's

Most recently the landings of both whelk and scallop dropped substantially, from 430 t in 1988 to just over 230 t in 1990 for whelk (Fig. 6), and from 480 t in 1987 to also about 230 t in 1990 for scallop (Fig. 8). Provisional figures for 1991 and 1992 suggest that the whelk landings are stabilizing at between 230 and 265 t, while scallop landings continued to decline to a mere 90 t in both 1991 and 1992 (a decrease of about 80% from the mid-1980's).

For scallop, sufficient evidence exists to conclude that the alarming decrease in landings is due to a depletion of the stocks, especially on the western grounds (see the section on seasonal fluctuations in the landings). Contrary to scallop, the state of exploitation of the whelk stocks has never been studied in detail, at least not in the North Sea. Therefore, it is difficult to identify the precise reason for the decline in the landings. The recent drop in whelk landings per unit effort (discussed later), and the dwindling auction prices, which fell roughly 25% despite an almost 50% decrease in landings (see next section), suggest that both biological and economic factors may have contributed to the decline in whelk landings.

Trends in Gross Returns and Auction Prices

Ever since the early 1950's, the Belgian mollusk "fisheries" have been of minor importance in terms of both quantities landed and financial returns to the fishermen. In the 1950's and early 1960's, whelk and scallop represented <0.4% of the overall yield of the Belgian sea fisheries (all finfish and shellfish landed by Belgian trawlers in Belgian ports) (Fig. 5), and <0.3% of the sales figures in the auctions (Fig. 11).

This situation changed, at first in the late 1960's with the rise of the whelk landings, and again in the mid-1970's with the rise of the scallop landings. Since then, the contribution of whelk and scallop to the total sea fisheries yield has fluctuated between 2.0 and 3.5%, and their share in the sales figures has fluctuated between 1.0 and 1.5%.

The gross returns of whelk increased from BEF0.3–1.0 million (BEF1 = US$0.03) in the 1950's and the early 1960's to BEF7.0–10.0 million in the late 1970's and the 1980's. Record sales figures were reached in 1983 and 1984, with almost BEF13.0 million (0.6% of the total sales figure for all finfish and shellfish landed in Belgium).

Nominal auction prices of whelk (not adjusted for annual inflation) varied considerably throughout the 1950's and the 1960's from BEF3.5 to 9.5/kg. From the early 1970's to the early 1980's they almost tripled, to over BEF28.0/kg, then fell again to between BEF17.0 and 22.5/kg (Fig. 12).

Deflated auction prices (adjusted to 1950 prices, using a compound pluri-annual inflation index), show little or no long-term trends. Even the sharp rise in whelk landings from the mid–1960's to the mid–1970's had no major impact on prices. Rather surprisingly, the recent drop in landings was not accompanied by an increase in the auction prices. Since 1984, deflated

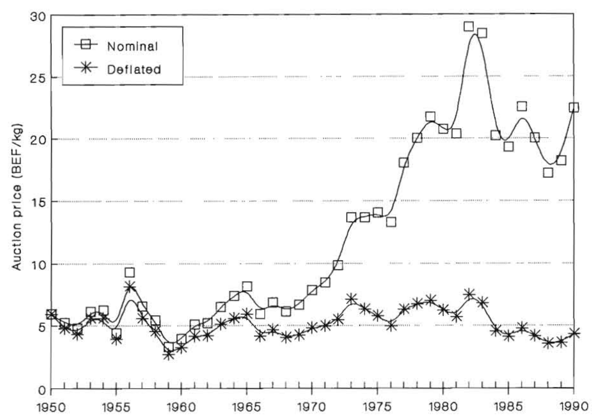

Figure 12
Nominal and deflated auction prices (BEF/kg) of whelk, *Buccinum undatum*, 1950–90.

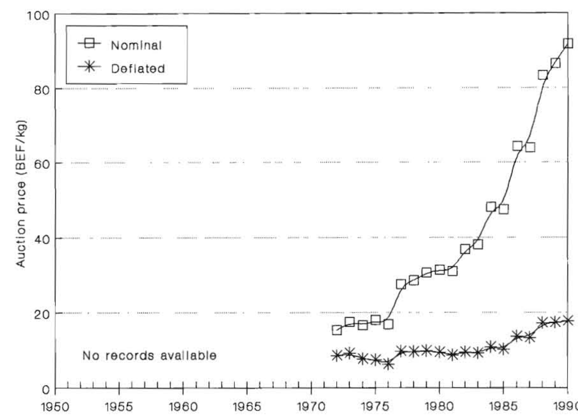

Figure 13
Nominal and deflated auction prices (BEF/kg) of scallops, *Pecten maximus* and *Chlamys* spp., 1950–90.

prices have been far below the average for the preceding 15 years, and in 1988 they almost reached a historical minimum (Fig. 12). Whether this is due to market saturation is unclear, but it almost certainly enhanced discarding by the fishermen which, in turn, may have put some pressure on the landings.

Whelk always has been among the cheapest of fisheries products, outvalued by almost all other finfish and shellfish, except for some ill-reputed species such as horse mackerel, *Trachurus trachurus*, and flounder, *Platichthys flesus*.

Data on gross returns and prices per kilogram of scallop are available from the early 1970's onwards. At that time the demand for scallop on the local market was poor and the auction price low, at about BEF15.0–18.0/kg. Since then, nominal auction prices increased almost continuously, to a peak value of BEF91.5/kg in 1990. Deflated auction prices also showed an upward trend, from BEF6.5–10.0/kg in the 1970's and early 1980's to over BEF17.0/kg in the late 1980's, a doubling of their market value in <10 years (Fig. 13).

Nowadays, scallop ranks in the top ten of the most expensive fisheries products, behind turbot, *Psetta maxima*; anglerfish, *Lophius piscatorius*; halibut, *Hippoglossus hippoglossus*; sole; brill, *Scophthalmus rhombus*; brown shrimp; lobster; Norway lobster; and lemon sole, *Microstomus kitt*; but ahead of some "renowned" fisheries products such as haddock, cod, plaice, and ray.

Increasing landings combined with increasing prices made the gross returns of scallop rise quickly, from <BEF5.0 million in the mid-1970's to >BEF20.0 million in the 1980's. Scallop had an outstanding year in 1986, with a sales figure of BEF37.5 million (1.2% of all finfish and shellfish auctioned).

Over short periods and under relatively stable market conditions, there appears to be a close inverse relationship between landings and auction prices, for both whelk and scallop. In the long term, however, this relationship is overshadowed by the major changes in the market situation, which occurred over the past decades. The increase in demand for scallop in the mid-1970's, for example, created a much larger sales potential for this species and, as a result, the market was able to absorb much larger quantities, without any drop in the auction prices (Fig. 13).

Present Status of the Fisheries

Seasonal Fluctuations in Landings and LPUE's

Seasonal fluctuations in landings and landings per unit of fishing effort (LPUE[1]) are well documented for whelk and scallop for the years 1981–90. The available database includes total and species-directed effort (in numbers of voyages, hours fished, and HP corrected fishing hours) as well as quantities landed by area, month, gear type, and vessel class. Discussing or even summarizing all the data would be beyond the scope of this publication. The focus, therefore, will be on two representative examples, beam trawl landings of whelk from the North Sea and scallop from the English Channel, with some side comments on the other fisheries.

North Sea whelk landings by flatfish-directed beam trawlers show a clear seasonal pattern, with peak values

[1] The LPUE's in this paper were calculated from effort data for vessels actually landing whelk or scallop, and not from effort data for the fleet as a whole. Unless stated otherwise, LPUE's are given in kg/hour trawling.

in autumn and early winter, usually between September-October and January-February (Fig. 14). In most years there is a second, much lower and much narrower peak in the landings around June. Roughly similar fluctuations appear from the data series for the *Nephrops*-directed otter trawlers operating in the central North Sea and for the flatfish-directed beam trawlers in the English Channel.

The whelk LPUE's of North Sea beam trawlers display a seasonal pattern similar to that in the landings. In the early and mid-1980's (i.e., before the decline of the whelk landings), the average LPUE's during the peak season varied from 0.6 to 2.8 kg/hour trawling for the 51–100 GRT vessels, from 1.7 to 3.6 kg for the 101–150 GRT vessels, from 3.5 to 6.5 kg for the 151–200 GRT vessels, and from 4.5 to 7.9 kg for the largest vessels. The data available for vessels ≤50 GRT were too erratic to be included in this comparison. Data for individual seasons show a clear, almost linear relationship between GRT and LPUE (Fig. 15). In recent years, however, the peak LPUE's dropped by about 50% as compared with the figures for the early 1980's. This may be due to a decline of the stocks or to an increase in discarding by the fishermen in response to the relatively low auction prices of whelk (see previous section on trends in gross returns).

Scallop landings by beam trawlers fishing in the English Channel show marked seasonal fluctuations, with sharp peaks between December–January and April–May (when, from a gastronomical point of view, the scallops are at their best, because of the fully developed gonads or "coral"), and marked lows during summer (Fig. 16). Similar patterns are recorded for the Celtic Sea and the Irish Sea, albeit slightly shifted in time. Peak landings usually occur between January–February and April–May in the Celtic Sea, and between March–April and May–June in the Irish Sea. Beam trawling in the Irish Sea is a strictly seasonal activity, with 55–85% of the fishing effort concentrated in the period March–June. The seasonal pattern of the North Sea scallop landings is irregular, with respect to both rhythm and range of the fluctuations.

Before the decline of the scallop landings in 1988, peak season LPUE's in the English Channel ranged

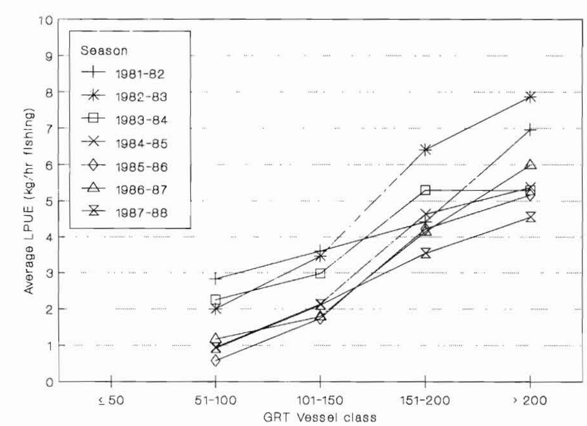

Figure 15
Relationships between beam trawler GRT and peak season LPUE's of whelk, *Buccinum undatum*, landed from the North Sea.

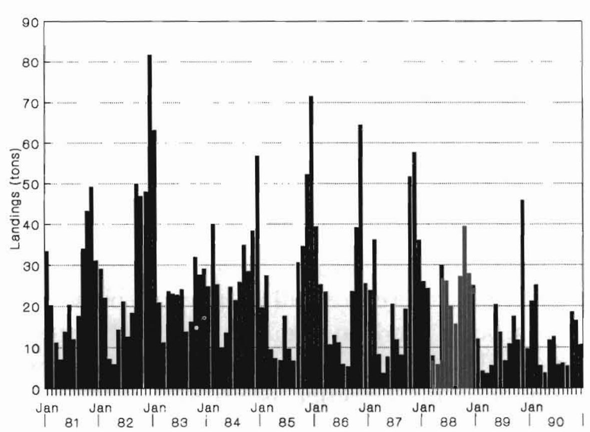

Figure 14
Monthly landings of whelk, *Buccinum undatum*, from the North Sea by flatfish-directed beam trawlers, all vessel classes combined, 1950–90.

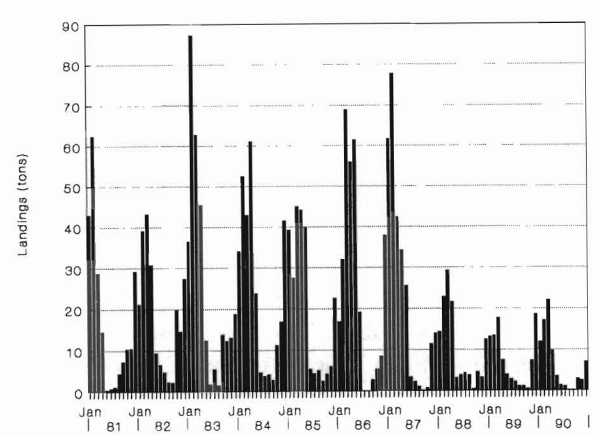

Figure 16
Monthly landings of scallops, *Pecten maximus* and *Chlamys* spp., from the English Channel by flatfish-directed beam trawlers, all vessel classes combined, 1950–90.

from 3.9 to 6.3 kg/hour trawling for the ≤50 GRT vessels, from 3.2 to 8.3 kg for the 51–100 GRT vessels, from 2.6 to 6.7 kg for the 101–150 GRT vessels, and from 3.5 to 17.8 kg for the 151–200 GRT vessels. Data for the vessels >200 GRT were too few to allow any comparison. The data series for individual seasons show a broad and hardly conclusive array of relationships between GRT and LPUE.

Since 1988, the peak season LPUE's of scallop in the English Channel fell by >70% as compared with the early 1980's. Similar drops occurred in the North Sea and the Celtic Sea but not in the Irish Sea. The severe drop in the LPUE's in scallop-rich areas such as the English Channel and the Celtic Sea gives reason for concern since it may be symptomatic of an alarming depletion of the scallop stocks.

Management Regulations

Except for the regulations set by the Commission of the European Union (which are legally binding to all EU member countries), national or local management regulations that specifically apply to the Belgian mollusk fisheries do not exist. For great scallop there is a minimum landing size of 110 mm (ICES Sub-area VIId - English Channel East) or 100 mm (all other areas), measured across the largest width of the shell (EU Regulation 3094/86, Section 5). No minimum landing size regulations exist for queen scallop or whelk.

For the time being, there are no catch or effort restrictions for any of these species (at least not in the areas accessible to the Belgian trawler fleet). This may change, even in the near future, especially if the depletion of the scallop stocks continues along the trend set during the most recent years.

Management regulations not directly aimed at mollusks, such as the temporary closing of fishing areas for plaice or sole to avoid overshooting the TAC's, may, however, have an immediate impact on the landings of other species as well, including whelk and scallop.

Mollusk Trade and Consumption

The First Traces of Mollusk Consumption

The documented history on mollusk consumption in the area nowadays called Belgium, goes back to the early days of the Roman occupation (1st century A.D.). Excavations on inland Gallo-Roman sites revealed fragments and complete shells of several marine mollusk species (Gautier, 1972, 1983; Cordy, 1981; Peuchot, 1981; Van Neer, 1988, 1990), amongst which oysters were by far the most abundant. Oysters were highly prized by the Romans, and the presence of a variety of oyster that is typical for the English Channel and the British Isles, suggests they were sometimes traded over long distances.

Strong evidence on the methods used to transport the oysters is lacking, but they most probably were firmly tied up to avoid loss of liquid, and then covered with seaweed to keep them cool and moist (Peuchot, 1986). Even under these conditions, the shelflife of oysters is relatively short, which led to the hypothesis that they were brought quickly to destinations, possibly by mounted couriers (Peuchot, 1981).

Mussels and cockles, *Cerastoderma edule*, were first found in remains from the 1st to 3rd centuries (Gautier, 1972, 1983; Peuchot, 1981), and whelks in funeral tombs and rubbish dumps from the 2nd to 4th centuries (Gautier, 1972). Mollusks probably were consumed even earlier by prehistoric populations living along the coast, but, as yet, no faunal remains from such sites are available.

Archeozoological investigations on medieval and early post-medieval sites, covering a time span of >1,000 years between the 6th and the 17th century, yielded numerous fish and shellfish remains, including oysters, mussels, cockles, whelks, and periwinkles, *Littorina littorea* (Gautier, 1983; Gautier and Van der Plaetsen, 1986; Van der Plaetsen, 1985a). The finds confirm that, throughout the ages, there has been an active trade in fisheries products, including mollusks, between the coastal areas and the inner parts of the country; Van der Plaetsen (1985b) provides a comprehensive review.

Rise and Fall of the Oyster Growing Industry

The local history of oyster growing dates back to the end of the 18th century, when the first oyster growing farm was established near Ostend (Halewyck and Hostyn, 1978). Young oysters were imported from the United Kingdom and grown to a commercial size in man-made ponds. The industry flourished during the "Belle Epoque" period, from about 1865 to 1914, with annual exports of up to 30 million of the internationally renowned "Ostendaises" or "Royal d'Ostende" to France, Russia, the Balkans, Germany, and Austria. On the eve of World War I, the oyster industry counted 26 growing farms and employed >270 people (Halewyck and Hostyn, 1978).

After World War I, the oyster growing industry started to subside. Many oyster parks had been severely damaged during the war, and the supply of young oysters was badly affected by a disease outbreak in the English rearing farms (Halewyck and Hostyn, 1978). First attempts to revive the industry and to actually rear oysters in the Ostend Sluice-dock (an inland seawater basin, originally designed to "blow out" the harbor) were fairly successful, but they were thwarted by World War II.

New trials, especially in the 1960's, largely failed because of increasing problems with water quality and with competitors (barnacles and *Crepidula*) of the seedling oysters (Halewyck and Hostyn, 1978). The last oyster growing company ceased its activities in the early 1980's.

Trends in Mollusk Consumption Since the 1950's

In 1990 (the most recent year for which exhaustive trade and consumption statistics were available), Belgium imported about 34,200 t of live, fresh, frozen, or dried marine bivalves and gastropods (product weight, not converted to live weight), and 2,600 t of canned or likewise preserved mollusks (including cephalopods). The total live weight of the bivalve and gastropod imports (all commodity groups combined) was estimated at about 37,500 t, a figure that exceeded the grand total of the Belgian finfish and shellfish landings by roughly 6,500 t. The overall value of the imports (all commodity groups, cephalopods excluded) amounted to BEF2.6 billion, i.e., 11.5% of the grand total for all finfish and shellfish imports for human consumption in 1990.

The 1990 imports of bivalves and gastropods (excluding canned products) comprised, amongst others, 30,630 t product weight of live or fresh blue mussels; 1,590 t of oysters (European flat oyster, *Ostrea edulis*; and various species of cupped oysters, *Crassostrea* spp.); and 900 t of fresh or frozen pectinids, mainly from the Netherlands (92.0%) and France (4.5%). Imports from non-EU countries represented <0.5% of the total.

Compared with the imports, the 1990 exports were small: 280 t of marine bivalves and gastropods (product weight) and 700 t of canned mollusks (including cephalopods). The exports (all commodity groups, cephalopods excluded) had an overall value of about BEF120 million (just over 1.5% of the total export sales figure for fisheries products). Part of the exports consisted of canned mollusks, imported as raw products and processed by the local food industry.

The availability of import and export statistics varies widely among species in both detail and time span covered. For mussels, the data series goes back to the immediate post-war years, but the imports and exports of many other species, such as pectinids, venerids, and most cephalopods, were not recorded as separate items in the trade statistics until 1988. Long-term trends in the national consumption of individual species or species groups, therefore, can be given for only a limited number of them.

The total consumption[2] of blue mussels fluctuated between roughly 19,000 and 25,000 t/year from the early 1950's until 1980. In 1981 it increased in one stroke by 5,400 t, and since then it has balanced between roughly 25,000 and 32,000 t/year, with a peak of 31,800 t in 1982. The annual per capita consumption of mussels followed a similar trend (Fig. 17). Most blue mussels were, and still are, imported from the Netherlands. In 1990 Belgium took 30,320 t or almost one-third of the Dutch mussel production, together with much smaller quantities (usually <3% of the imports) from Denmark, France, Germany, Ireland, and occasionally the United Kingdom.

The annual consumption of flat and cupped oysters has fluctuated widely over the past decades, from 560 t to just over 2,900 t. Since 1986 it has remained fairly stable at about 1,600 t/year. In 1990 the oyster imports comprised 53 t of live flat oysters and 1,530 t of "Other oysters," mainly supplied by the Netherlands (54%) and France (43%).

The total consumption of "Other mollusks" (a wide variety of bivalves, gastropods, and cephalopods including, amongst many others, whelk and scallop) increased almost linearly from 830 t (live weight) in 1965 to 4,250 t in 1990.

The data series on canned mollusks (including cephalopods) shows considerable variations. Consumption figures fluctuated between 1,000 and 1,600 t/year (product weight) from the mid–1960's to the mid–1970's and, after a sharp increase to almost 2,100 t in 1977, between 1,400 and 2,200 t/year in the late 1970's and throughout the 1980's.

The annual per capita consumption of mollusks (including cephalopods) ranged from 2.5 to 3.1 kg live weight from the mid–1960's to the mid–1970's, then

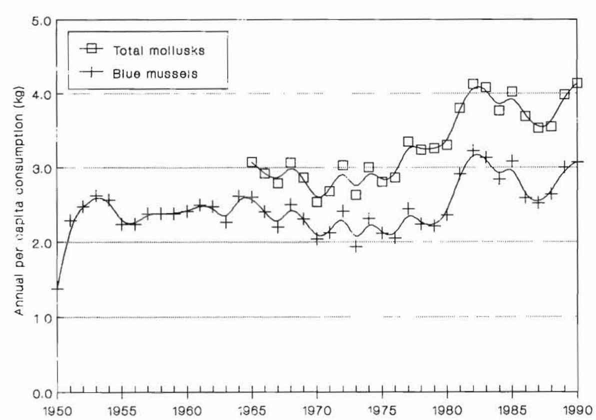

Figure 17

Annual per capita consumption (kg live weight) of mollusks (including cephalopods), and blue mussel, *Mytilus edulis*, 1950–90.

[2] Consumption figures were calculated as Imports + Landings – Exports, and unless stated otherwise, are given in metric tons live weight per annum.

quickly rose to just over 4.1 kg in 1982. Within the next 5 years it declined to about 3.5 kg, but most recently it increased again to 4.1 kg (Fig. 17). The exact share of bivalves and gastropods therein is difficult to establish, except for the years 1988–90, when they represented 91–93% of the annual mollusk consumption. A tentative breakdown by species or species group of the 1990 per capita mollusk consumption is given in Figure 18.

Mollusks, as a whole, contribute about one-fifth to the total consumption of finfish and shellfish in Belgium, a figure that has hardly changed over the past 25 years. Flat and cupped oysters are usually eaten raw from the shell, with a dash of pepper and a few drops of lemon juice; mussels and whelk are most often steam-boiled with a mixture of onions, leek, celery, and parsley. The domestic consumption of other bivalves and gastropods is low and, strictly speaking, there are no traditional, regional preparations for these species. Restaurants throughout the country, however, may offer a wide choice of dishes, most often inspired by French, Spanish, or Italian gastronomy, of which mollusks are an essential ingredient.

Mussels, scallops, queen scallops, cockles, and sometimes carpet shells, *Venerupis* spp., are also used in salads, and in sauces accompanying, for example, cooked or fried whitefish. Worth mentioning, and typically Belgian, is the so-called "sauce à l'Ostendaise," a creamy dressing with brown shrimps and mussels, which goes particularly well with sole.

The Future

Against the cheerless background of declining scallop stocks and a dwindling whelk market, the immediate future of the Belgian mollusk "fisheries" does not look promising. If the current overexploitation of the scallop stocks continues, the EU may be compelled to set precautionary TAC's to protect them. In that case, the Belgian fisheries may well be pinned down to very low or even zero TAC's in a number of fishing areas, which would put a serious constraint on the development of any specialized scallop fisheries.

Attempts to develop such a fishery were undertaken by the Fisheries Research Station (Ostend, Belgium) in the mid-1980's (Anonymous, 1986). The experiments consisted of rigging a series of scallop dredges to the beam of a beam trawl, and to fish for scallop on the offshore scallop grounds in the English Channel. Although the results were promising, with catches of up to 22.5 t of scallop in 16 days at sea (i.e., an average of 1.4 t/day), the technique was never used on a commercial scale, mainly because fishermen lacked interest in it.

The traditional, almost conservative, attitude of many fishermen and shipowners with respect to target species and fishing techniques has been a major impediment to the diversification of the Belgian sea fisheries. Beam trawling for plaice and sole currently pays well. In the long term, however, focusing on a small number of species may well prove not to have been the best way to guarantee the future of the Belgian fishing industry.

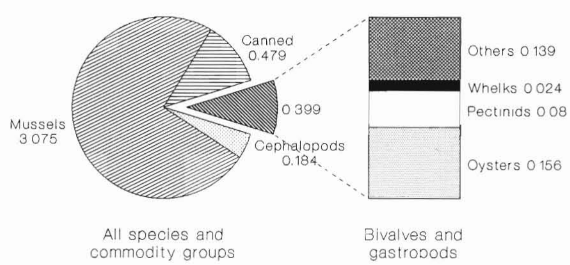

Figure 18
Tentative breakdown of the 1990 per capita consumption of mollusks (kg live weight) by species or species group.

Acknowledgments

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Molluscan Fisheries and Culture in the Netherlands

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ABSTRACT

Trade in mollusks in the Netherlands dates from the 1st century and the Middle Ages. In the late 18th century, 145 vessels harvested oysters, *Ostrea edulis*, in the Zuiderzee; landings were about 14 million oysters/season. After 1850, landings began to decline sharply. Blue mussels, *Mytilus edulis*, had been fished mainly for local and regional consumption, but by 1870 an export market for fresh mussels developed. Much of molluscan production has since been exported to Belgium and France. Mussel culture began to develop after 1865. Mussel growers dredged seed on wild banks and sowed it on their culture plots in Zeeland and the Wadden Sea. There now are 77 mussel firms; their fleet consists of 82 vessels. After harvest, the mussels are transported to Yerseke and sold by an auction. A small-scale fishery for cockles, *Cerastoderma edule*, existed in which fishermen raked the cockles in knee-deep water. In the early 1960's, the hydraulic dredge was developed for harvesting cockles and production increased thereafter. There currently are 43 cockle dredge boats; most cook the cockles at sea. Fisheries for periwinkles, *Littorina littorea*; whelks, *Buccinum undatum*; and softshells, *Mya arenaria*, became substantial in the second half of the 19th century. The whelks were harvested with dredges. Whelks now are harvested only in the North Sea as a by-catch of flatfish beam trawlers. Softshells were dug commercially with forks and spades on tidal flats until about 1952, but now only small quantities are dug. Each year, from 700–1,500 t of *Crassostrea gigas* are produced. During the past 5 years, average annual production of mollusks was about 80,000 t of blue mussels, 50,000 t of cockles, and 5 million oysters, with an average landed value of DFL120 million (US$70 million). In 1989, the molluscan fishery employed 1,520 people directly and 1,940 indirectly. As the demand for mussels is increasing, mussel prices probably will increase. The molluscan industry feels increasingly threatened by government measures aimed at reducing the impact of the fishery on the environment and wildlife.

Introduction

The first indications of molluscan trade in the Netherlands date from the first century and the Middle Ages. Mussel and oyster shells have been found in Roman settlements (Lauwerier, 1988) and in 7th and 8th century excavation sites (Groenman-van Waateringe and Van Wijngaarden-Baker, 1990). The locations were 80 and 200 km from the coast. For centuries, the production was low and mainly destined for local markets.

A relatively low domestic consumption of seafood, at present (1993) about 12.5 kg/person/year, has been below the production capacity of the coastal waters, and has left considerable scope for export. Beginning in the last century, an export market for bivalves was developed and it has since expanded to its present scale. Export and transit of live shellfish is facilitated by the favorable conditions for storage of live mollusks and crustaceans offered by the Oosterschelde estuary and the proximity of a large market in Belgium and France, both countries with a tradition of seafood consumption. The average production of mollusks during the last 5 years was about 80,000 t of blue mussels, *Mytilus edulis* (2,900,000 bushels), 50,000 t of cockles, *Cerastoderma edule* (1,375,000 bushels), and 5 million oysters *Ostrea edulis* (25,000 bushels), with an average landing value around DFL 120 million (US$70 million). In 1990, the total turnover of the mollusk sector was about DFL 300 million (US$165 million). In 1989, the molluscan fishery employed 1,520 people directly and 1,940 indirectly. Imports of mussels, cockles, and oysters make up for bad harvests and allow a stable supply of the export market. Additionally, other live shellfish are imported, stored, and exported.

Production Areas

The Wadden Sea (Fig. 1A) is a shallow, inshore sea in the north of the country separated from the North Sea by a row of islands. It extends from the Netherlands to Denmark. The Dutch section covers 2,500 km^2, 67% of which are intertidal sandflats, separated by tidal channels. In the western part, the area of intertidal sandflats is small (about 37%) compared with the eastern part (73%). Due to its large area, its shallowness, and the occurrence of drifting ice in cold winters, the wild and cultured mollusk populations are regularly decimated by ice scouring and exposure to waves and currents. The water is relatively turbid; under normal (no storm) conditions the suspended solids concentration is 15–50 mg/l. The salinity is 30–32‰. The mean tidal amplitude is 1.5 m in the western part and 3.0 m in the east. Until 1932, the Zuiderzee was an inland sea with an estuarine character. That year the fresh lake Ijsselmeer was created by the construction of an enclosure dike for safety and land reclamation (Fig. 1A). Mollusk culture and fisheries were thereafter restricted to the marine Wadden Sea.

In the Province of Zeeland, in the southwest of the country, three estuaries (from north to south), the Grevelingen, Oosterschelde (Eastern Scheldt), and Westerschelde (Western Scheldt) were initially fed by the Rivers Rhine, Meuse, and Scheldt (Fig. 1B). In the last decades, these estuaries have been modified considerably during a flood protection scheme (Dijkema, 1988). Only the Westerschelde has retained its estuarine character. In 1971, the Grevelingen estuary was dammed off on two sides. It is now named Lake Grevelingen, a rather shallow (2–10 m) stagnant marine lake, covering about 100 km^2, with a stable and artificially maintained salinity. The Oosterschelde (310 km^2, 54% of which are intertidal sandflats) was closed in 1986 with a permeable flood barrier. The resulting reduction of the tidal exchange lowered the current speed by 30%, but did not depress the bivalve production capacity (Van Stralen and Dijkema, 1994). The tidal amplitude now lies between 2.00 and 3.00 m. The water temperature varies between 0° and 22°C and the salinity between 28 and 30‰. The Westerschelde used to be an important area for mussel culture and fisheries. Land reclamation has caused the mussel plots and wild mussel banks to disappear. Only cockles are now fished on the sandflats. Populations of edible mollusks are also found in the shallow part of the North Sea coast to a depth of about 20 m. The area is exposed to strong wave action during gales. A few locations are sheltered by sandflats. When bivalve beds survive the winter storms there, they are fished. Plans exist to create mussel culture plots in this area.

Oyster, Mussel, and Cockle Fisheries, and Early Culture Trials

Oysters

In the early 18th century, the European flat oyster, *Ostrea edulis*, was collected and dredged in the eastern Wadden Sea between Schiermonnikoog Island and the mainland and in the western Zuiderzee between Texel and Wieringen (Fig. 1A). As early as 1714, imports of seed oysters from Denmark were reported (Hoek, 1911), illustrating that recruitment was unable to keep up with exploitation of the beds. The variable stock size must be attributed mainly to losses due to freezing and ice, shifting sandflats, and the capricious reproductive success of the flat oyster in the Zuiderzee, where in many summers the water temperature does not exceed 16°C. This minimum temperature is necessary during a couple of weeks for successful spawning and settlement.

In the last quarter of the 18th century, 145 vessels were reported fishing in the Zuiderzee: 60 from Texel, 25 from Zoutkamp, and 60 from Schiermonnikoog (Hoek, 1911). According to Paludanus (1776), the fishermen collected oysters on foot at low tide, dressed in leather waders and often using wooden boards attached to their feet to prevent sinking in the mud. The catch was collected in wooden troughs which were dragged over the flats. In this manner up to 2,000 oysters could be collected per day. Use of long-toothed iron rakes is also mentioned. Iron dredges, first reported in 1740, were initially used only in the eastern part of the Zuiderzee. The dredges were similar to those used in the German Wadden Sea and probably also to those later described by Moebius (1877). They were 4 feet wide and had bags with undersides made of 2" iron rings (Fig. 2). A small ship towed 2 or 3 dredges, a larger ship 4 dredges. As the ships had no winches, the dredges were often emptied into small boats towed behind the ships.

To be profitable, dredger landings had to be at least 100,000 oysters per season. This means that in the second half of the 18th century, landings in the Zuiderzee must have amounted to roughly 14 million oysters or more per season. The fishermen mostly held their catch for shorter or longer periods on private "oyster banks" demarcated with wooden poles. Paludamus (1776) describes 60 such beds off Texel, each measuring 25 ha. Undersized oysters were fattened, and marketable oysters were kept there until the

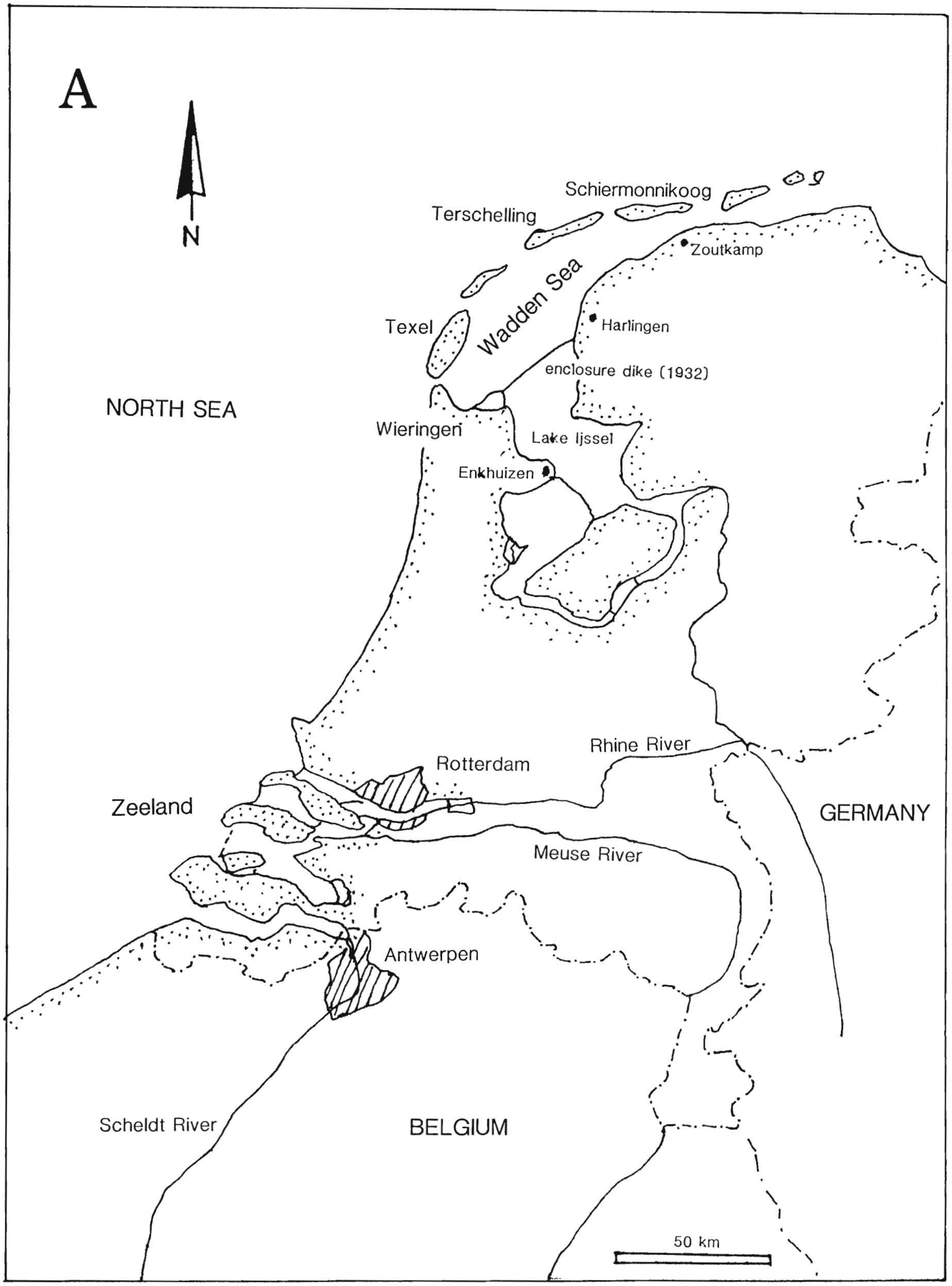

Figure 1A
The Netherlands' major mollusk fishing and production areas: Wadden Sea and Zeeland.

season opened. The oysters were shipped mainly to Amsterdam and to the German cities Bremen and Hamburg and even as far as the Baltic cities Riga and St. Petersburg.

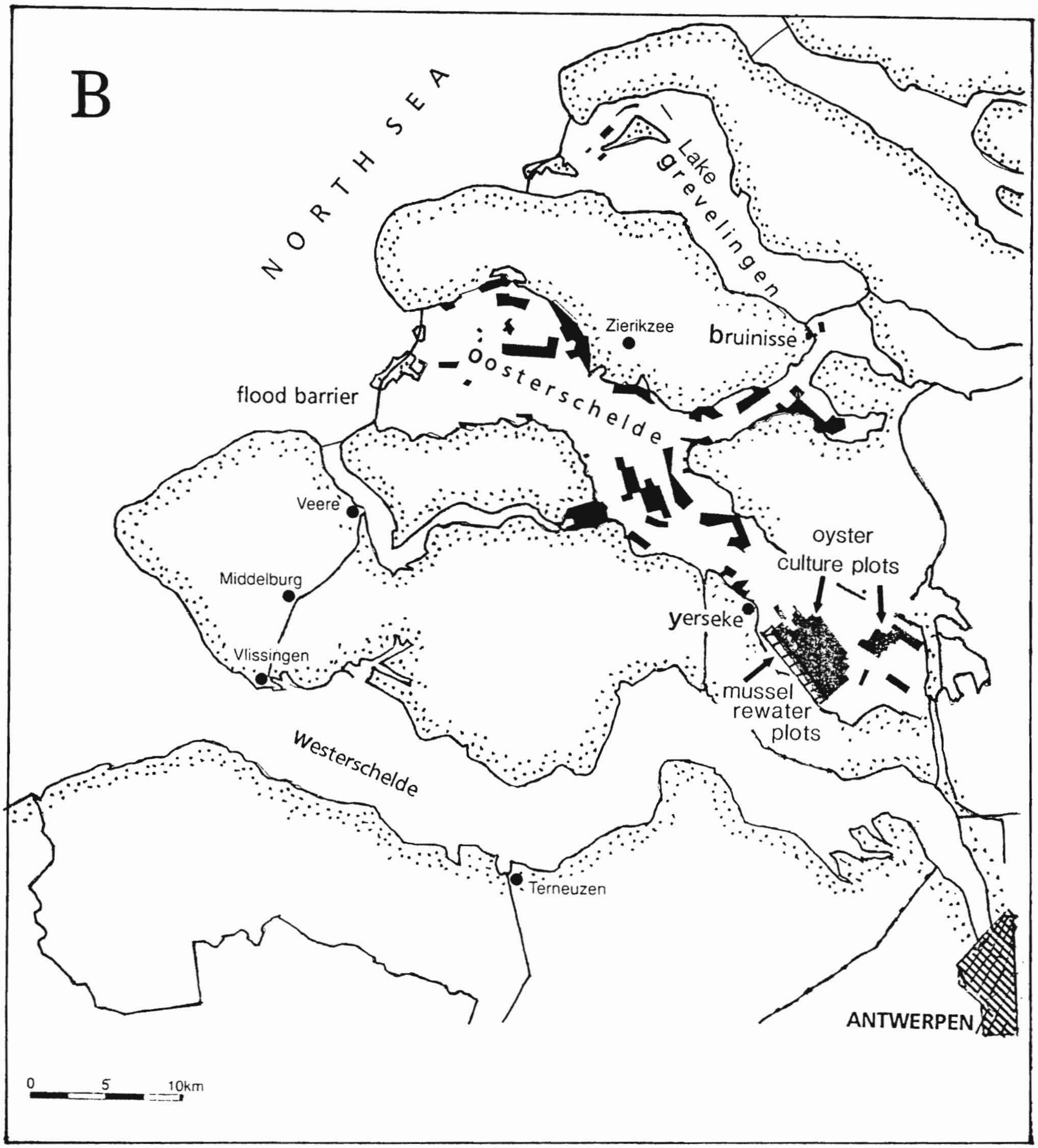

Figure 1B
The Zeeland mollusk production and fishing areas: Lake Grevelingen, Oosterschelde, and Westerschelde. Culture plots for mussels are shown in black. Culture plots for oysters are marked as are the mussel rewater plots.

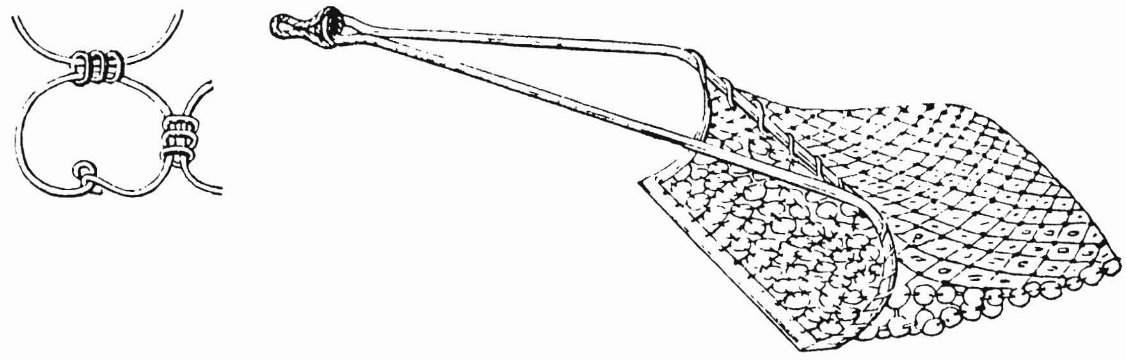

Figure 2
Typical 19th century oyster dredge, used in the Dutch and German Wadden Sea. The iron rings on the underside were 6–7 cm in diameter (after Moebius, 1877).

After 1850, landings began to decline sharply, probably due to a combination of high fishing pressure, mortality, and failing recruitment (Hoek, 1879). After 1856, rarely more than 300,000 oysters were landed per season at Texel, which caused poverty among the fishermen. Initially, attempts were made to restore the oyster production by sowing on sheltered beds the undersized specimens from the large imports of consumption oysters from Denmark, England, and Scotland. Between 1859 and 1884, other unsuccessful restocking trials were made on different locations in the Zuiderzee, this time with specially imported seed oysters weighing about 40 g. In 1884, considerable investments were made in seed oysters that were relaid in an area off the island of Wieringen where the public fishery was banned. The trial failed due to natural causes and also poaching, as supervision was insufficient. The plots were eventually restored to the public fishery (Hoek, 1901).

A culture experiment off Texel in 1930, with 6 million seed oysters, likewise failed. After a few more vain attempts, the flat oyster disappeared from the Wadden Sea between 1940 and 1950. It is supposed that, in addition to stock depletion, hydrographic changes caused by the closure of the southern Zuiderzee in 1932 may have played a role.

In the estuaries in Zeeland, exploitation of the wild oyster banks also dates from the early 18th century. Also here, overexploitation occurred, and chronicles mention imports of seed oysters from the British Isles (Baster, 1762). The principal fisheries were found in the Oosterschelde off Zierikzee and in the Grevelingen off Bruinisse. Later, in the 19th century, the eastern part of the Oosterschelde and the Westerschelde also made lucrative oyster grounds for fishermen from Yerseke and Tholen. Oysters were fished mainly with long-toothed iron rakes. Natural fluctuations in stock size were less pronounced than in the Zuiderzee, which can be attributed to higher water temperatures and more sheltered beds. Nevertheless, the oyster beds were gradually overexploited and the industry became increasingly dependant on imports.

In 1825, a Fisheries Authority for the Zeeland waters was installed by the Government to regulate the rapidly deteriorating fisheries (Fokker, 1926). Fishing for spat and seed oysters was forbidden, and a fishing season was introduced, starting in October. Despite these regulations, that were hardly complied with, the stocks remained small, and massive imports had to supplement the landings. Around 1850, 200 ships were only exceptionally able to land more than 1 million oysters/year among them. Increasingly, pleas were heard in favor of a switch to oyster cultivation (Hoek, 1902). By 1886, all public oyster fisheries had been closed and culture plots were rented. Since 1971, a wild oyster fishery has again existed in Lake Grevelingen. Until the oyster disease bonamiasis broke out in this lake in 1988, between 5 and 7 million oysters were harvested there each year. At present, the landings have fallen to about 1–2 million flat oysters per year. Wild banks of Pacific oysters in the Oosterschelde are fished for seed oysters and, to a lesser extent, for market size oysters.

Mussels

Until the middle of the 19th century, blue mussels, *Mytilus edulis*, were fished mainly for local and regional consumption, with mussels from the Zuiderzee being peddled in Amsterdam and from the Westerschelde sold in Antwerpen. In the second half of that century, when the population of the big cities grew rapidly due to industrial development, the demand for inexpensive protein-rich nutrition increased and mussels appeared to be an attractive food. By 1870, an export market for fresh mussels also developed. The principal destinations were Belgium and England. From 1913 to 1929, those two countries imported 25,000–38,000 t and 2,700–4,500 t, respectively, per year. Between 1924 and 1929, from 1,000 to 3,100 t were also exported annually to France, and 2,400–3,000 t went to Germany. Apart from this, an unknown quantity of mussels was taken every year in the Westerschelde by Belgian fishermen, after an 1839 treaty with Belgium had granted equal fishing rights in that estuary to citizens of both countries. In the 19th century, mussels from the Zuiderzee were fished mainly from Wieringen, Harlingen, and Zoutkamp and shipped to northern Great Britain and the cities of Bremen and Hamburg. Mussels from Zeeland were sold in Antwerpen by the fishermen themselves and were also shipped to London from Vlissingen, Zierikzee, or Rotterdam. The development of steam-powered vessels after 1860 further enhanced the fresh mussel exports.

In the first half of this century, the mussel fishery in the Zuiderzee was mainly in the hands of fishermen from Wieringen with 30 ships and from Texel with 12 ships (in 1910). They used small sailing craft, equipped with one or two iron dredges. Hand rakes were also used.

The development of mussel culture in Zeeland after 1865 created a strong demand for small seedling mussels. As mussel seed is usually scanty in the southern estuaries and abundant in the Zuiderzee, a large mussel seed fishery developed each year in the latter area. Around 1880, about 80 ships from Zeeland fished the banks of mussel seed in the Zuiderzee. This met with protests from the local fishermen, who saw themselves outnumbered by their southern colleagues.

In 1910, the first steam-powered dredger appeared from Zeeland; it harvested ten times as much as the traditional sailing ships (Hoek, 1911). In the following years, protests increased and the number of licenses for steam dredgers was limited. The increasing trend in mussel consumption culminated during World War I (1914–18), when navigation at sea was limited and seafood was scarce. Between 1897 and 1930, the total national mussel production was around 40,000 t, with 5,000 t coming from the Zuiderzee. A large share of these mussels were exported to Germany. In 1918, the production was 120,000 t of wild-captured and 4,500 t of cultured mussels (Havinga, 1932).

Motorization steadily increased and, during 1926–28, 20 steamships landed mussels. By 1932, almost all the fleet was motorized.

Through time, fishermen from Wieringen also harvested mussels to be sold as fodder to duck farms at the borders of the Zuiderzee and, as with starfish, mussels were also used as manure on farmland. Furthermore, mussel shells still serve as spat collectors in oyster culture, and farmers use them to stabilize marshy soils.

Currently, the only existing wild fishery is that on seed and half-grown mussels. It is restricted to about 6 weeks in the spring and 2 weeks in the autumn. Between 50,000 and 150,000 t of seed and half-grown mussels are fished in most years on subtidal and intertidal wild banks by the mussel growers, to be sown on their culture plots in Zeeland and the Wadden Sea.

Cockles

A small-scale fishery for cockles, *Cerastoderma edule*, has existed since the second half of the 19th century. Cockles were fished in knee-deep water (0.1–1 m) with gear that is still in use: The "beugel" or "klauw," a long-stemmed rake with teeth of 5–6 cm and a net bag, about equal to that described by Von Brandt (1972). The rake is dragged through the sand by a belt around the waist of the fisherman, while he holds the stem over his shoulder and slowly works backward with a to-and-fro movement. Around 1870, cockles were fished off Texel and Terschelling, and shipped to England after being cooked and preserved with salt or vinegar, or both (Van der Vlis, 1975).

Around 1930, cockles worth DFL10,000 were landed per year. Most of the fishery took place between Harlingen and Terschelling (Ypma, 1962). Production declined after closure of the Zuiderzee in 1932. The cockle fishery in the estuaries in Zeeland was smaller than that in the Wadden Sea. The sandflats in the Westerschelde were also worked by a number of Belgian fishermen who sailed their catch upstream and sold it directly in Belgium. Practically the entire Dutch production was exported fresh to France and Belgium and, before 1965, as conserves to England. The exported quantities in both areas were small and variable initially but increased substantially in the 1950's, when up to 20 ships fished in the Wadden Sea. Some had adopted the British method to flush the cockles out of the sand with the aid of the ship propeller.

In the early 1960's, the hydraulic dredge was developed, using a water jet to dislodge the cockles from the sediment in front of a steel blade that cut about 4 cm deep and scooped the cockles into the cage of the dredge. The full cage was hauled aboard and was emptied through a lid at the back. The investments to develop this system were possible because the ships could also be deployed successfully in the seed mussel fishery, and a substantial market for cooked deep-frozen cockles had been developed in Spain. After 1970, this type of dredge was gradually replaced by the present version that, apart from the pressure pipe for the water jet, is equipped with a suction pipe connected to the top of the cage of the dredge, through which the catch is continuously pumped aboard (Fig. 3). On deck, the catch passes rotating sieves in which sand, undersized cockles, and other small by-catch are separated from the catch and washed overboard. This development, which started in the Wadden Sea, has considerably increased the efficiency of the fishery, as the dredges need no longer to be hauled aboard.

Thanks to a growing demand for deep-frozen cockles on the Spanish market, the fishery has developed explosively: In 1960, 3 ships were fishing for cockles with suction dredges in the Wadden Sea and 2 in the Oosterschelde; in 1974, 24 dredgers, mostly adapted inshore barges, were active. In 1974, the government started to regulate the fishery, restricting the number of cockle fishing licenses to 35. In 1981, the cockle fleet numbered 32 ships, several of which had been designed especially for this fishery.

The Present Fishery

Currently, there are 36 cockle dredgers licensed to fish in inshore waters and 7 more to fish in the offshore area. The 36 licenses are owned by 15 companies.

Since the end of the 1980's until the 1993 season, almost all ships were equipped with two suction dredges 1 m wide, one at each side. As a reaction to drastic reductions of the fishing area by the government, the industry in 1993 voluntarily reduced the fishing capacity of the fleet by halving the width of the dredges. Most dredges can operate to a water depth of 10–13 m, but fishing depths of 20–25 m are possible. As cooking cockles is cheaper at sea than on land, most dredgers are equipped with continuous, conveyor-belt cookers. The cockles are cooked during low tide, when the tidal flats cannot be fished. Cooking is permitted only in designated areas where the microbiological water quality is checked regularly by the government and where piles of empty shells on the bottom cannot pose problems for shrimp beam trawlers.

Before cooking, the cockles are spread out on deck and immersed in seawater for a few hours to de-sand. A part of the catch is landed fresh and cooked in conserve factories. There are two specialized cooking ships with deep-freezing capacity. The cooked cockles are shucked on vibrating screens; the empty shells are dumped overboard. After the fishing season, they are removed by commercial shell dredgers and are ground to fabricate grit used on poultry farms. The cooked meat, about 12–20% of the fresh weight of the cockles, is brought to the processing plants, where it is mainly canned (70%), or block-frozen or individually quick frozen (IQF) for export. There are 8 processing plants using continuous pressure cookers. The plants, most of them located in

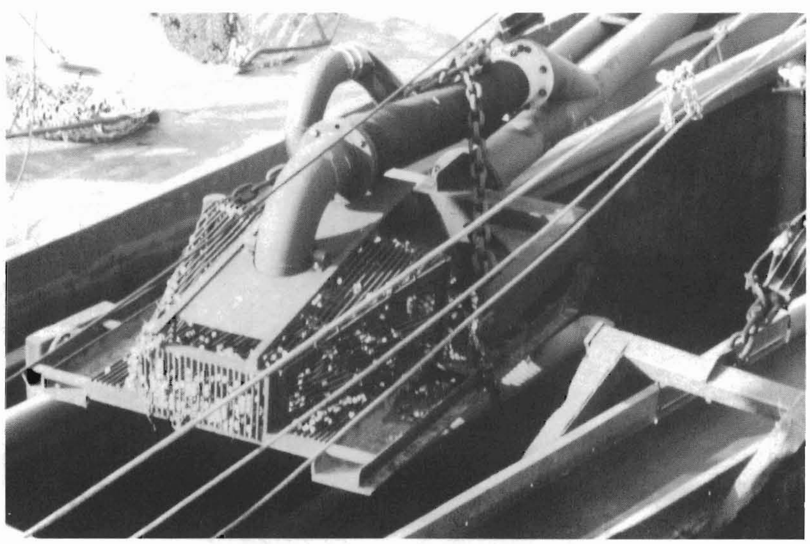

Figure 3
Hydraulic dredge (1 m wide) for harvesting cockles. It is attached to double 6–10" suction and pressure pipes at both sides of the ship. On board, the catch is separated from the water in a washing mill, through which undersized cockles and bycatch are washed back to sea.

Zeeland, are owned by the same fishing companies. They also process mussels and, during the off-season, fish and vegetables.

The government has taken a number of restrictive measures to regulate this rapidly expanding fishery, such as the maximum number of 36 licenses, maximum of 2 dredges of 1 m width per ship or one dredge of 1.2 m width, a minimum mesh width of 15 mm of the sieves and the cage of the dredge and, before every fishing season, decisions on closed areas and periods. Nevertheless, the fishing effort of the fleet has increased considerably during the last 10 years. This is a result of a series of technical developments. The ships have become larger, to about 40×10 m and a draft of only 45–50 cm, enabling them to fish cockle beds high in the tidal range. But the most important development has been an increase of the engine capacity of the ships and of the dredge pumps. This has permitted an increase in fishing speed from 2.5 to 4 knots with a proportional rise in fishing efficiency. The average catch of a cockle dredger is 130 t (3,575 bushels) of fresh cockles (20 t of meats) per fishing day during the first and most productive weeks of the fishing season.

In typical years, 10–20% of the cockles are captured in the southern estuaries, 0–20% on the North Sea coast in the south, and 50–80% in the Wadden Sea. Until 1991, the average landed value of the cockle meat was DFL25 million (US$13.37 million) per year. The annual value of the exported canned and deep-frozen product was about DFL100 million (US$53 million).

Cockle landings fluctuate considerably due to yearly differences in recruitment and mortality. Since 1991, closure of fishing areas by the government has also affected landings. Figure 4 shows cockle landings in fresh weight since 1946. They clearly demonstrate the increase in fishing effort of the last two decades. The reduced stocks after 1990 forced the cockle fishing industry to reduce its effort, so that in 1991 and 1992 a part of the cockle fleet was not used. To keep the exports going in 1992, cockles were imported from the United Kingdom, Ireland, France, and Denmark.

The manual cockle fishery, which had declined in the 1960's, revived after 1986, when conserve factories started to pay attractive prices. Fresh cockles are also exported to Belgium and France. In 1988, 352 licenses for the manual cockle fishery were issued to professionals and amateurs. In 1989, the maximal number of licenses was restricted to 90, only for professionals. Hand-cockling is practiced as a part-time occupation. The same gear as described above is used. Usually a

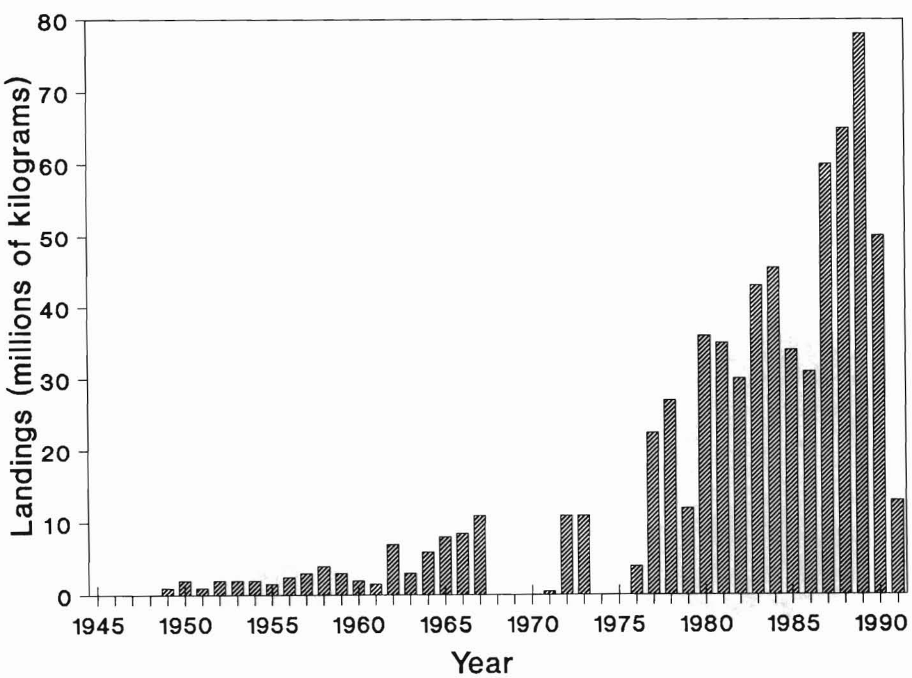

Figure 4
Cockle landings in fresh weight for 1946–92. No data are available for 1968–70 and 1974–75. Note the strong increase after 1960 following development of mechanical dredging and other technical improvements.

boat is used to reach the sandflats and to transport the catch. The landings vary with the size of the cockle stocks and, until 1993, amounted to between 2 and 10% of the national landings. In contrast with the mechanical cockle fishery, hand-cockling is permitted year-round. A hand-cockler has about 1.5–2 hours to dig on a tidal flat per tide. He removes cockles from about 100 m^2 and gets about 800 kg (22 bushels), that adds up to a catch of roughly 100 t (2,500 bushels)/man/year. In 1991, 1 kg of fresh cockles yielded about DFL0.80 (US$0.43). By 1993, the price had gone up to DFL2.00 (US$1.14).

The Future

The mollusk industry feels increasingly threatened by government measures that are aimed at reducing the impact of the fishery on the environment and wildlife. The main fishing areas, the Wadden Sea and the Oosterschelde, have been declared natural reserves. Fisheries on seed mussels and cockles arouse protests from nature preservationists, who claim that wild mussel and cockle beds are damaged. In years with small mussel and cockle stocks, the industry is accused of depleting food for bivalve-eating birds, such as eider ducks, *Somateria mollissima*, and oystercatchers, *Haematopus ostralegus*. Substantial sections of the intertidal flats in both areas are closed to the fishery. Additionally, a certain percentage of the wild mussel and cockle biomass must be reserved for birds. In years with small stocks, this will bring along serious restrictions and, in extreme cases, even complete suspension of these fisheries. The predominantly intertidal cockle fishery will suffer most from these measures. Fortunately for the mussel industry, 70–80% of the seed mussels are captured subtidally. The mussel growers, however, prefer intertidal seed for its hardiness.

Miscellaneous Mollusk Fisheries

Fisheries on periwinkles, *Littorina littorea*; whelks, *Buccinum undatum*; and softshells, *Mya arenaria*; became substantial after the general rise in seafood consumption in Europe in the second half of the 19th century. In 1900, the combined landed value of these species in the Zuiderzee amounted to DFL100,000 (Hoek, 1901). Between 1935 and 1950, a small fishery on the common Atlantic slippersnail, *Crepidula fornicata*, existed in the Oosterschelde. In 1941, during the war, this species was used to make a protein concentrate and later for shell grit production. This fishery was subsidized to help oyster growers control this pest.

In 1909, 140 ships from Wieringen fished periwinkles in the Zuiderzee, that abounded in vast eelgrass, *Zostera marina*, fields and on mussel banks around that island. The total yearly landings from dredging, bag-netting, and hand-collecting periwinkles were around 2,100 t. The fishery was so intensive that the size of the animals declined and regulation was considered. Periwinkles were exported live to Belgium, France, and England. This fishery nearly disappeared after the wholesale decline of the eelgrass in the early 1930's.

In Zeeland, where the tidal difference is much larger than in the Zuiderzee, periwinkles were collected mainly on tidal flats and dike slopes during low tide. Between 1892 and 1895, 60–98 t of periwinkles were landed per year. In some instances, plots were leased from the government for collecting. After 1950, the periwinkle stocks began to decline, labor costs became too high, and the fishery eventually disappeared in the 1960's. Now, all periwinkles are imported, mainly from Ireland, by four firms in Yerseke. They are stocked in basins (Fig. 5), where they are selected, packed, and exported mainly to Belgium and France.

The fishery on whelks, which were sold fresh and cooked, developed to an appreciable scale in the second half of the 19th century. In years when mussel and oyster fisheries were low, it served as a supplemental source of income for mussel and oyster growers who dredged them on their culture plots. Between 1920 and 1935, about 35 sailing ships were dredging whelks in the Zuiderzee, using traditional mussel and oyster dredges. They caught between 180 and 500 t per year, which in 1925 commanded DFL0.16/kg. In 1950, 94 t were landed, worth DFL1.42/kg. After 1950, 30–50 t/year were landed in the Wadden Sea area. In the 1960's, the whelk populations declined, and the fishery came to an end around 1970. At present, whelks are fished on only a small scale in the North Sea, mostly as a bycatch of flatfish beam trawlers. Fishing with pots or creels, as in Great Britain and France, is not practiced in this country. Since the mid-1980's, whelks are shucked, deep-frozen, and exported, mainly to Japan. In 1991, about 200 t of meat were exported. The 1991 landing price was DFL 1–1.5/kg (US$0.53–0.80) fresh weight.

Softshells were dug commercially with forks and spades on the tidal flats in Zeeland until about 1952. In 1926 and 1930, respectively, 279 and 50 t (10,200 and 1,800 bushels) of this species were landed in Zeeland, yielding about DFL0.05/kg. They were consumed mainly in France. In 1952, the landings were only 1.8 t (66 bushels), fetching DFL0.15/kg. After 1952, the species was still collected in the Westerschelde by Belgian fishermen who sold their catches directly in Belgium. There were no fishery records for this species in the Dutch Wadden Sea. At present, only tiny lots of softshells are collected incidentally and sold on special request.

When mollusks on the European market are scarce, even undersized cockles, with meats weighing <1 g,

Figure 5
Storage of flat oysters in tidal basins in Yerseke. These brick basins were constructed at the end of the 19th century when oyster culture in the Netherlands began.

become attractive for the fishing industry. Also, the cut trough shell, *Spisula subtruncata*, which occurs in dense banks off the North Sea coast, is then fished. This happened on a modest scale in 1989, but in 1992 and 1993, when there was a general scarcity of cockles, several thousand tons of this species were fished with cockle dredges, then cooked, shucked, and exported to Spain and Italy. Also, a small fishery on *Spisula solida* now exists. Since about 1990, scallops, *Pecten maximus*, have been fished by 3–5 fishermen who had stopped beam trawling for flatfish because prospects were uncertain. Scallops hardly occur on the Dutch coast, but they are fished off the Scottish coast and the French and British coasts of the Channel. Multiple scallop dredges of the British type are used.

Fishery Regulations

In 1707, the first governmental measures were taken in Zeeland to regulate the mussel and oyster fisheries. In this case, the aim was to reserve the fisheries for the local fishermen. The first measures on a national scale to protect oyster stocks were probably taken by the French occupants at the end of the 18th century.

In 1925, national legislation became more concrete. Fishing in Zeeland was, in principle, available for all Dutch citizens. The regional fisheries authority was installed to deal with repeated complaints about overexploitation of the fish and shellfish populations. It imposed minimum sizes and closed seasons for most fishes and shellfishes and regulated the fishing gear. Mussels had to be captured with the so-called "slagrijf," a long-toothed rake. The use of dredges needed special permission and toothed dredges were forbidden. Mussels <3 years old were protected, oysters had to be larger than 7.5 inches and could only be fished between 1 October and 31 February. Each fisherman had to pay for his fishing license and had to paint a registration number on his ship. Inspectors were employed to enforce the regulations.

At present, molluscan fisheries and cultivation are regulated by the Fishery Law, which is implemented by the Ministry of Agriculture, Nature Management, and Fisheries. Management policy was, until recently, aimed at stock conservation but, increasingly, nature protection is being taken into account. Fisheries for mussel seed and cockles are regulated by season and area. Before each fishing season, the Netherlands Institute for Fisheries Research (RIVO-DLO) makes stock assessments that form the basis for the regulations. Since 1991, the mussel industry has applied its own quotation system to distribute the catch among the growers and to avoid excessive dredging on the seed beds. In 1993, for the first time, the mussel growers abstained from fishing for seed mussels in autumn to spare the natural banks.

Oyster and Mussel Culture

Flat Oyster Culture

After 1865, Zeeland oyster stocks and banks became increasingly overexploited, and the supply of seed oysters from Scotland decreased. A change from a wild fishery to cultivation seemed the only way to maintain a fishery. In 1866, a group of well-to-do potential private investors in oyster culture had made a vain appeal to the government to rent them oyster banks that they wanted to convert to culture plots. After a visit to a French governmental oyster culture project in the Bay of Arcachon, this group invited the director of this project to come and assess the possibilities for a cultivation project in the Oosterschelde. He judged commercial culture to be an economically feasible activity.

Finally, the government was convinced, and decided to suspend the fishery and to rent out suitable grounds in a shallow area east of Yerseke, the Yerseke Bank (Fig. 1B). On 6 May 1870, the first public rental of culture plots took place. The 260 plots, with a total area of 3,085 ha, were rented for around DFL 7.00/ha/year (Havinga, 1932). In 1886, the last public fishing grounds became culture plots.

Local fishermen, who could not afford to rent culture plots, to their dismay saw their fishing grounds disappear into the hands of wealthy outsiders. In the decade to follow, many of them became employees in the oyster growing firms; others managed to rent small plots where they produced seed oysters from spat, which they sold to the growers. The new oyster growing firms invested large sums in buildings, ships, tidal storage basins, and further equipment. The first motorized ships appeared in 1885, and motorization was common by 1910. Culture techniques and design of equipment were largely derived from existing operations in France and England (Buch, 1886). The new industry boomed, causing explosive economical and demographical development in the small village of Yerseke (Van Ginkel, 1988). Its population grew from 770 inhabitants in 1849 to 4,469 in 1885.

In 1882, the rent sum for culture plots, which was established by public bidding, started to rise from DFL7 to DFL110/ha/year. This was so high that it affected the profit. Meanwhile, oyster production in Europe increased. By 1889, the market became saturated and prices dropped, forcing growers to increase their production. After 1885, the growth rate and meat quality of the oysters in the Oosterschelde began to decline. P. P. C. Hoek (1902) who, as the governmental adviser in fishery affairs, was asked to investigate the decline, blamed overstocking of the plots. He estimated that the annual production after 1895 was around 50 million oysters. To reduce food competition, he concluded, the oyster stocks on the plots had to be reduced drastically. In later years, biologists have believed that the carrying capacity of the production area is sufficient to sustain an annual maximum production of 25 million oysters of satisfactory meat quality.

More problems followed in 1902 after contaminated oysters were consumed in England. It caused an outbreak of typhoid fever, with some people dying. This created an "oyster scare" in all of Europe, and oyster consumption collapsed. In 1906, the Dutch government imposed sanitary control measures on mollusks and the coastal waters and certification, but oyster exports did not recover before 1911. The national production then rose to 20–40 million oysters/year, and remained about stable until 1962.

In 1926, the introduction of the slipper snail created a serious problem for the oyster industry in Zeeland. The numbers of this gastropod, which had been introduced into Great Britain in 1880 with a shipment of oysters from the United States, increased explosively in Europe and thrived on oyster beds in the Oosterschelde. In the colder Wadden Sea, it did not form a stable population, despite massive introductions with seed oysters from Zeeland in 1930–34. Large numbers of slipper snail spat, settling on the shells sown out for oyster spat collection in summer, overgrew and killed the oyster spat. Additionally, the large amount of slipper snails on the culture plots competed with oysters for food and depressed their growth and meat quality.

In 1935, measures were taken to combat the slipper snails. A premium was given for dredging and landing them. In 1937, the use of shells for spat collecting was temporarily forbidden, and the oyster growers reverted to spat collection on limed rooftiles, which made a less attractive settling substrate for slipper snail larvae. Steady dredging appeared the most successful way to reduce slipper snail numbers. Its numbers stabilized after 1950, and the gastropod is now a nuisance only on a number of oyster and mussel plots in the Oosterschelde and Lake Grevelingen after consecutive warm summers. In the Wadden Sea, slipper snails are rarely encountered.

The extremely cold winter of 1962–63 killed most of the oyster stock, and ice destroyed the holding facilities in the Oosterschelde. Recovery of these facilities and of a new oyster stock were postponed, as the government had decided to dam off the Oosterschelde and convert it to a freshwater lake to reduce the risk of flooding (Dijkema, 1988). Most of the about 160 oyster growers quit the industry and were indemnified by the government. Only 10 larger and more diversified growing firms, that could afford to do so, remained in business for the time being. As the stock of parent oysters was destroyed, they had to import seed oysters from France and other countries. Originating in the Atlantic Ocean, these oysters are not hardy enough for the Dutch winter climate. Culture was therefore limited to fattening between April and December.

O. edulis culture techniques did not change essentially between 1880 and 1962. The most obvious developments occurred in spat collection. Initially, roof tiles coated with a mixture of lime and fine sand were used. They were placed in the tidal zone in June and July at locations with reputed good spatfall. In 1885, as many as 30 million roof tiles were placed. After 1904, cockle shells, which required far less labor and could be sown in deep water, were increasingly used as collectors. Between 1924 and 1930, 40,000–50,000 m^3 of cockle shells were sown each summer.

The hardy and slowly disintegrating cockle shells, that persisted and accumulated on the oyster beds for several years, however, appeared to host the survival stages of the fungus *Ostracoblabe implexa* that causes the feared "shell disease." During warm summers, the fungus causes black malformations on the inside of shells of live oysters and eventually kills them. For this reason, and also because enormous amounts of slipper snails settled on the cockle shells, their use was banned in 1936. After 1939, only the use of mussel shells, which degrade much faster, and limed roof tiles was allowed. Owing to high labor costs, roof tile use ended after 1963. Since then, only mussel shells have been used. Spat was removed from the roof tiles by hand, mostly by women, in April of the year following spatfall. Spat were then reared on trays in the tidal zone for another season before being relaid on shallow culture plots. Around 1960, oysters were relaid 2–3 times per growth-cycle of 4–5 years. In 1955, there were 152 oyster culture firms. A more detailed description of oyster culture in the 1950's is given by Korringa (1976a).

In 1976, the government changed its policy and decided to conserve the tidal exchange in the Oosterschelde with a permeable flood barrier (Dijkema, 1988). As adjacent waters had already been dammed off for safety reasons or had been reclaimed, mollusk culture had disappeared there, except in Lake Grevelingen. For the remaining oyster growers, who all resided in Yerseke, there was again a perspective that now the Oosterschelde would remain open. Unfortunately, the recovery of the flat oyster culture was prevented by another cold winter in 1978–79 that killed part of the oyster stock, and by an outbreak of the disease bonamiasis in 1980 after the protozoan *Bonamia ostreae* was introduced from France (Grizel, 1985). The government placed a ban on oyster farming in the Oosterschelde and forbade direct transport to nearby Lake Grevelingen, where a population of winter-hardy native oysters had survived the damming. Thanks to this measure, the oyster population and with it the 16 existing oyster growers and fishermen, were temporarily spared the consequences of the disease. In 1988, bonamiasis was finally brought into the lake with infected oysters, after the ban on relaying in the Oosterschelde had been lifted. Until that moment, the lake had produced 10–15 million consumption oysters/year, half of which were cultured.

Present Status

Flat oysters are reared on bottom plots in the inland section of the Oosterschelde (1,700 ha) and in Lake Grevelingen (380). On special plots, spat are collected on mussel shells, sown mostly in densities of 30–60 m^3/ha (345–690 bushels/acre). The shells are sown in June-July as soon as water temperatures above 18°C have prevailed for several days and sufficient numbers of eyed larvae are counted in the water. After settlement, the mussel shells, with attached spat, are kept on the plots for 1 year. Then they are dredged up and relayed, usually to deeper plots with better conditions for growth. Market size is reached in 4–5 years from settlement at a weight of 70–100 g. Labor and fishing costs are considered too high for the old-fashioned intensive culture with 2–3 relayings. Also, the cleaning of the bottom of the plots by dredging to remove shell debris, formerly a duty to minimize the risk of shell disease, is now often neglected. At present, only a few million flat oysters are produced per year in the Grevelingen and the Oosterschelde. Annual mortality due to bonamiasis varies between 30 and 90%. The sharp decline of flat oyster production is partly offset by substantial imports from countries like Ireland, Greece, Turkey, Canada, and even Chile, which allows exports to continue. Prices have risen sharply. The oysters, which are mostly small (60–80 g) because bonamiasis affects oysters of 70 g and heavier, fetch a wholesale price of DFL0.7–1.0 (US$0.37–0.53) apiece (1993). This high price considerably reduces the sales volume, as many consumers change to the much cheaper Pacific oyster, *Crassostrea gigas*, that costs only DFL0.30 (US$0.16) apiece on the wholesale market.

Culture and Fishery of the Pacific Oyster

After the outbreak of bonamiasis, oyster growers in the Oosterschelde were forced to change to the culture of the Pacific oyster. In Yerseke, it is usually called by its French name, "creuse," which means hollow. This species has been cultivated and fished in the Oosterschelde on a small scale since the late 1970's. It was deliberately introduced after imports of the related Portuguese oyster, *C. angulata*, had been severely reduced owing to an outbreak of iridiovirus, causing gill disease (Comps, 1983). In 1964, small amounts of 10 mm spat of the

Kumamato and the Myagi strains, imported from Japan, were stocked on a shallow plot in the Oosterschelde. The growth rate appeared excellent, and in the following year the weight of the oysters increased from 25 to 100 g. The decision to introduce *C. gigas* had been based on the assumption that the summer water temperatures in the area would not be warm enough for successful recruitment, as had been the case for *C. angulata.*

The contrary proved true. Probably due to local heating of the seawater in shallow places on the tidal flats at low tide during sunny weather, spawning and spatfall of *C. gigas* can be profuse in the shallow eastern section of the Oosterschelde, where water temperatures can reach 24°C during warm summers. About 10 years after the introduction, wild, reef-like Pacific oyster banks developed on sandflats in the intertidal zone and on dike slopes. Natural recruitment is sufficient to maintain this population, which is probably the northernmost in Europe. Wild spat is dredged and seeded on the culture plots, and there is also a small commercial nursery using imported spat. Most of the spat, however, is collected on mussel shells, that are usually broken to avoid floating and are sown in the tidal area. The grow-out plots lie just below the mean low water mark, but increasingly deeper plots are used.

Each year, about 700–1,500 t (19,250–41,250 bushels) of *C. gigas* are cultured, fished, and collected by hand. Most oysters are exported to Belgium and Germany and, thanks to good meat quality, even to France, which itself produces around 130,000 t of "creuses" per year. After successive warm summers, *C. gigas* has expanded strongly in the Oosterschelde and is considered a pest by mussel growers, as it settles on the mussels and lowers their market value. To prevent expansion of this species into the Wadden Sea, transfer of mussels from the Oosterschelde to that area has been forbidden. Since 1986, *C. gigas* is also found in the Westerschelde and, increasingly, in Lake Grevelingen.

The Future

Bonamiasis is now endemic to the entire southern area and probably will remain flat, causing heavy losses. This will be almost prohibitive for flat oyster culture and fisheries as a sole occupation. A production of a few million oysters per year, from fisheries and cultivation, as a sideline for diversified shellfish firms, will probably be the most that is feasible unless research, underway in the Netherlands and France, is able to develop a strain of flat oysters resistant to bonamia. Use of genetically improved seed oysters would also require adoption of more intensive, suspended culture methods, now applied by only two firms. The industry, however, does not seem to be much inclined to innovate or to invest in future development. Import, storage, and subsequent export of flat oysters are expected to dominate the Dutch oyster industry. As things stand, *O. edulis* will remain a scarce and expensive product, destined for the luxury market. Prospects for the Dutch Pacific oyster culture depends largely on the development of demand on the European markets. As its culture in France appears to have about reached its limits and European demand is expected to increase further, there will probably be room for some expansion in the future.

History of Mussel Culture

Harvested mussels have been stored and rewatered on the sea-bottom since the early 18th century, but official records mention rental of mussel culture plots by the southern regional fisheries authority since 1827 in the Westerschelde and since 1865 in the Oosterschelde (Fokker, 1926). In 1930, the first culture plots were created in the northern Zuiderzee. Earlier, rentings had only incidentally taken place, for instance in the fertile and sheltered southern part of the Zuiderzee off Enkhuizen. This area was lost to mollusk culture and fishing, however, after its closure in 1932.

Large-scale development of Dutch mussel culture was not at first stimulated by market developments. After 1950, a disastrous outbreak of the "mussel parasite" *Mytilicola intestinalis* occurred following its introduction in 1948 in Zeeland with a shipment of mussel seed from Germany. This crustacean, living in the intestine of the mussel, developed explosively on culture plots in the Oosterschelde and caused large losses by weakening the mussels until they died. Production plummeted from 50,000 t (1.8 million bushels) in 1949 to just over 10,000 t (367,000 bushels) in 1953. To decrease the infection rate, lowering of the stocking density of mussels on the plots appeared a successful remedy (Korringa, 1957).

To maintain the total production, it was decided to expand mussel culture to the Wadden Sea. Analogous to the situation in the Oosterschelde in 1870, this operation required the closure of areas for the wild fishery, affecting about 20 mussel and shrimp fishermen from Wieringen and Harlingen. Some of them were indemnified by the mussel growers, while others were permitted to rent culture plots. In 1951, after trials by selected groups of growers from Yerseke and Bruinisse, a number of culture plots were made off Terschelling and Wieringen. By 1955, 55,000 t of mussels were produced in the Wadden Sea, and the production stabilized at around 60,000 t/year (2.2 million bushels) in the 1960's.

New culture plots in the Wadden Sea also became necessary because a number of growers, mainly from Bruinisse, had lost plots after the closure of sea arms with dams for flood protection. In 1966, some 195 mussel growers were active, 105 of whom were fulltime. Of these, 96 were based in Zeeland and about 15 in the Wadden Sea. By 1991, the total number of growers had decreased to 79, mainly by disappearance of firms without a ship and of small part-time growers. By 1990, the number of growers based in the Wadden Sea had decreased to four, and in 1992 only two were left. After 1955, the *Mytilicola* infection rate and mortality in Zeeland gradually decreased, a result of the lower seeding densities combined with the development of an equilibrium between host and parasite. *Mytilicola* is now occasionally found in low numbers in mussels without causing any harm.

Mussel seed has been traditionally fished in the Wadden Sea, as little spatfall takes place in Zeeland. During 1954–56 and 1990–92, mussel spat recruitment failed, causing great problems for the industry. The growers were then forced to buy hand-collected seed mussels from dikes or to import seed from Germany, Belgium, and even France. In the past century, mussel seed had also been imported repeatedly from Great Britain in years of bad recruitment (Drinkwaard, 1967). Short periods without mussel seed can usually be bridged by stocks on the culture plots, but when these had become exhausted by storms and bird predation, the shortage in 1991–93 became urgent for a number of growers who had no prime material. In spring 1992, a good recruitment occurred again.

The growth rate and meat yield of mussels in the Wadden Sea is higher than in the estuaries of Zeeland, especially on plots in the sea inlets, close to the North Sea. A drawback of the Wadden Sea as a culture area is the relative shallowness of most of its plots (1–4 m below low tide) and thus high vulnerability to wave action during storms. This allows considerable portions of the cultured mussels and the wild mussel banks in the tidal zone to be swept away during westerly storms in winter. This may happen once in several years, but sometimes, and especially in the last half decade, also in successive years. This is reflected by the highly variable mussel production of this area (Fig. 6). For this reason, the mussel growers prefer to rent a combination of productive but risky plots in the Wadden Sea and more stable, but less productive plots in the Oosterschelde. The European demand for mussels shows a steadily increasing trend and the Dutch mussel industry has benefitted for more than two decades from good prices. Figure 7 shows some economical aspects of the development of mussel culture since 1960. The

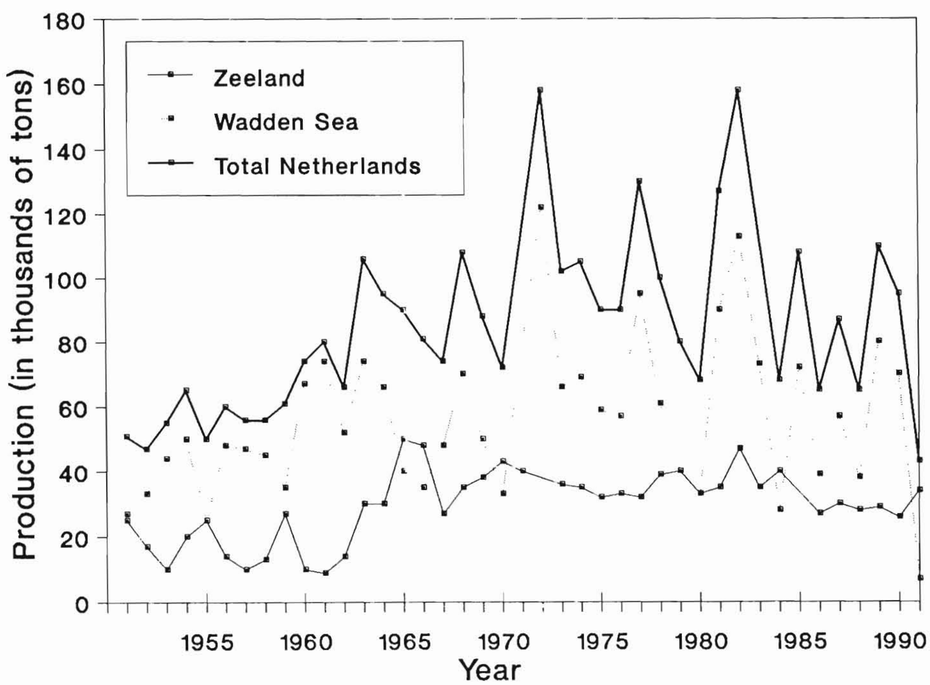

Figure 6
Mussel production in the Netherlands and in the production areas of Zeeland and the Wadden Sea, 1951–91. Note the difference in the variability of production in the two areas, a result of different susceptibility to storm mortality.

increase in prices and returns until 1986 can be ascribed to inflation. Thereafter, the price increased sharply due to shortages of mussels.

Present Status of Mussel Culture

There are now (1993) 77 mussel growing firms. Although 60–70% of the production comes from the Wadden Sea, all but two growers are native to and based in Zeeland. Originally, all growers were family enterprises, but this structure is declining. Increasingly more firms have their capital spread out over shareholders, and individual companies are taken over by other growers, mussel processing and trading firms, or multinational food companies. Currently, 460 culture plots in the Wadden Sea cover 6,000 ha, but only 3,700 ha of this area have adequate current speed and bottom condition to allow production. In the Oosterschelde, 345 plots cover 4,000 ha, of which 2,250 are productive. The average area rented per grower is 125 ha. The size of the plots is 7–25 ha, their water depth is mostly 3–10 m and ranges to 15 m. Wild seedling mussels of 2–3 cm or older and half-grown mussels of 3–4 cm length are dredged in May and September, mainly in the Wadden Sea. They are then relaid and reach market size within 1.5–3 years, depending on the productivity of the plot used. On the best plots, a meat yield of 30–35% of the fresh weight can be reached in August-September. The meat yield peaks in August-October and reaches 20–35% in the Wadden Sea and 17–30% in the Oosterschelde. The plots are rented from the government. The growers pay a total rent sum of DFL4.3 million (US$2.3 million)/year for all plots. Their contribution is proportional to the culture performance of their plots and to their share in the landings. Five governmental fishery inspectors supervise matters like the demarcation of plots, the seed mussel fishery, mussel harvest and transport, and determination of the culture value of plots.

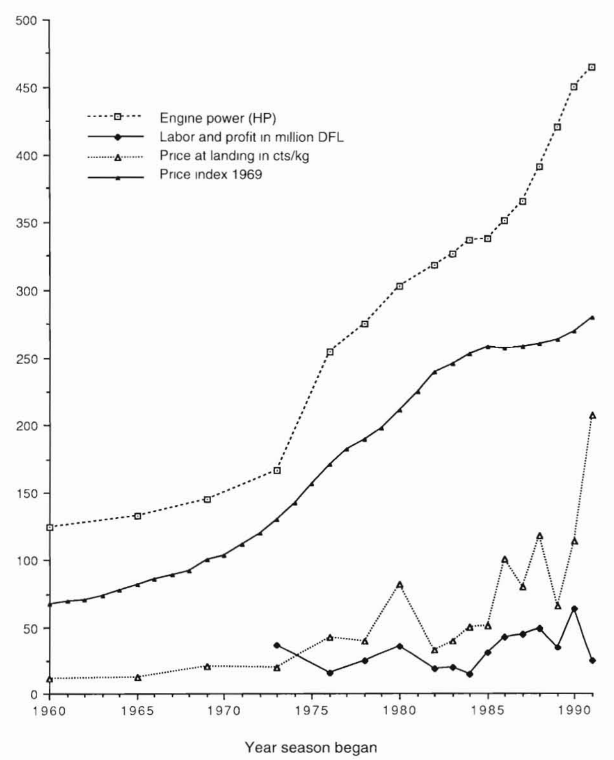

Figure 7
Economic and fleet development in the Dutch mussel growing industry, reflected in the average engine power, value at landing, the price (in cents/kg auctioned: 1 DFL = 100 cents), and the "Return to Labor" (total of wages plus net profits) since 1960. The low return to labor in 1991 is due to high expenses necessary to purchase mussel seed in Germany. The price index (1969 = 100%) shows the inflation during this period. Source of statistics: Netherlands Agricultural Economics Research Institute (LEI-DLO), Division of Fishery Economics.

The construction of the flood barrier in the Oosterschelde in 1986 reduced the current velocity and reduced production on a number of plots. On the other hand, the current reduction has made large areas suitable for mussel culture that had been useless before, due to excessive current speeds, i.e., above the upper limit of 60–80 cm/second at the bottom (Dijkema and Van Stralen, 1989; Van Stralen and Dijkema, 1994).

Causes of mortality in mussel culture are storm damage, which makes reseeding necessary on plots stripped of mussels by storms, and predation: 20,000–30,000 t (730,000–1,100,000 bushels) of mussels are consumed annually by a wintering population of 100,000–200,000 eider ducks in the Dutch Wadden Sea. Seagulls, *Larus argentatus*, and oyster catchers prey on spat and half-grown mussels on intertidal plots. Predation by shore crabs, *Carcinus meanas*, can affect thin-shelled small mussels, while mortality caused by starfish, *Asterias rubens*, can be dramatic, especially on deeper plots close to the tidal inlets. Like eiders, starfish can strip a culture plot of mussels in a couple of days, especially when these are thin-shelled. Eider ducks are protected and can only be scared away with noise in areas where this is permitted. Starfish are combatted with special rollers, after which they are killed with salt, freshwater, or by leaving them in the ship overnight. Mussel seed fished from intertidal plots is considered more resistant to predators.

Storm hazards and predation reduce overall culture efficiency. An average of 1 t of consumption mussels is harvested from 1 t of seed. It must be taken into account, however, that fished mussel seed contains 40–60% of tare. Silt, sand, and shell debris are not included in the statistics, whereas mussel production is registered without tare. This makes the real efficiency about twice as high. The low efficiency is partly caused by increased storm damage and bird predation during the last decade, in addition to increased fishing power of the ships. Efficiency can be improved by decreasing the storm risk. A number of the most exposed plots in the western Wadden Sea will be moved to more sheltered and deeper areas.

A typical mussel growing firm owns one ship. Only a small number of larger firms have two ships. The total mussel fleet consists of 82 "cutters" (Fig. 8). For the mussel seed fishery, cockle dredgers are also leased. Two mussel ships are convertible to the cockle fishery. The size of ships has increased markedly during the last 15 years. A modern cutter measures overall 35–40 m, has a width of 8–9 m, and draws 50–90 cm when empty. This enables the growers to catch mussels on plots and wild banks high in the tide zone. A cutter can carry 140–180 t (5,100–6,100 bushels). (The mussel industry always measures in "mussel tons" of 100 kg, based on barrels, used in the early days.) The ships have crews of 3, are driven by twin engines of 300–600 hp, and are equipped with bow-propellers, ship-to-shore telephones, and computerized positioning, echo-sounding, and satellite navigation equipment. The graph in Figure 6 gives an impression of the development of engine power during recent decades.

Mussels are harvested with four steel dredges about 1.9 m wide, operated by a hydraulic or pneumatic 8-drum winch (Fig. 9). When used on hard and sandy bottoms, the round steel ground bars of the dredges are provided with bolted-on 2x2 cm steel blades, the so-called "knives." To save labor and time and to decrease mortality by shell breakage, the system for unloading the mussels and simultaneously sowing them on the bottom has developed in the course of years from manual shoveling (in the 1950's) to conveyor belts with holes in the sides of the ship above the waterline (in the 1970's), and finally to a system by which water is pumped into the hold and the mussels are washed out through holes below the waterline. This system requires a double bottom and sides of the ship (Fig. 10). Under favorable conditions, a ship can be loaded with mussels within 4 hours and emptied in half an hour. The investment costs in a new ship are DFL 1.5–2 million (US$0.8–1.07 million). More detailed descriptions of the mussel industry are given by Havinga (1932), Korringa (1976b) for the 1950's, and Dijkema and Van Stralen (1989) for more recent years.

After harvest, the mussels are transported to Yerseke (Fig. 11), where the only mussel auction in the country (and probably the world) is operated by the Commodity Board for Fish and Fish Products (Fig. 12). The cargo of each ship is sold to the highest bidder among about 27 accredited mussel traders, of whom all but two are located in Yerseke. The purchased mussels are relaid on special rewatering plots rented by the traders. Situated directly south of Yerseke, this shallow, sheltered area has a firm, stable bottom and good, well-monitored water quality. There are 75 rewater plots of 5 ha. The mussels remain on the plots for 2 weeks, during

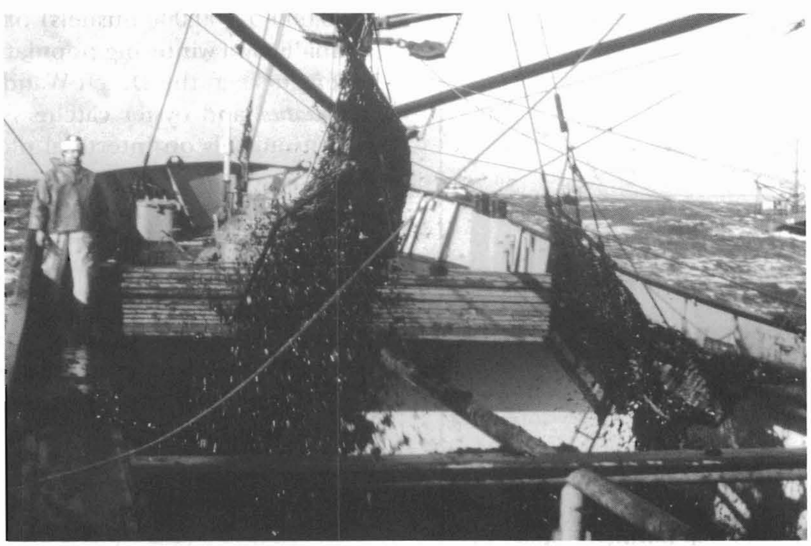

Figure 8
Mussel "cutter" dredging for mussel seed in the western Wadden Sea.

which they excrete ingested sand and mud and recover from stress caused by dredging and transport. Re-watering increases the shelflife of the mussels, while dead and broken specimens are eliminated by crabs, fishes, and seagulls. Additionally, the plots serve as "wet warehouses" for the traders. Finally, the mussels are dredged up carefully, in many cases placed directly into containers on deck, and are sailed to the processing plants. To allow the mussels to get rid of the last ingested sand, they are kept in the same containers in a vertical flow of UV-sterilized seawater for 4–7 hours (Fig. 13). Subsequently, they are de-clumped, rinsed, de-byssused, in summer chilled to 7–10°C, graded, and packed. About 70% of the production is sold fresh, and

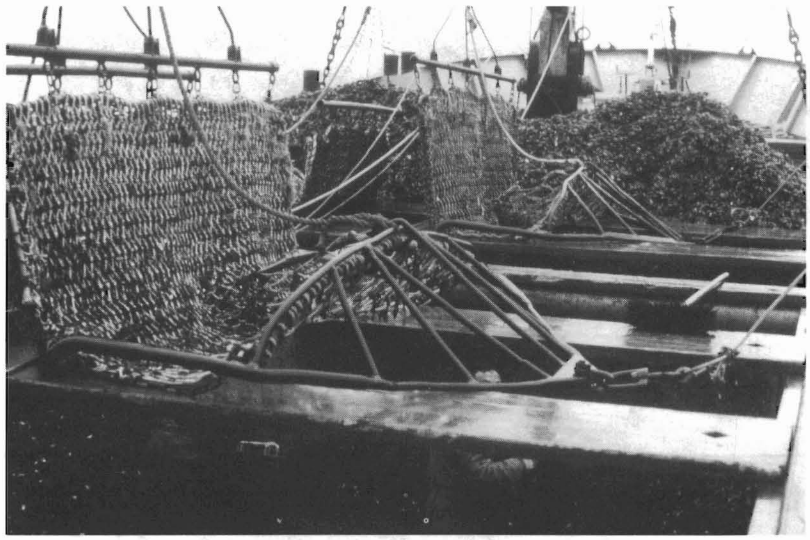

Figure 9
View of mussel dredges. They are emptied by raising the bar at their end.

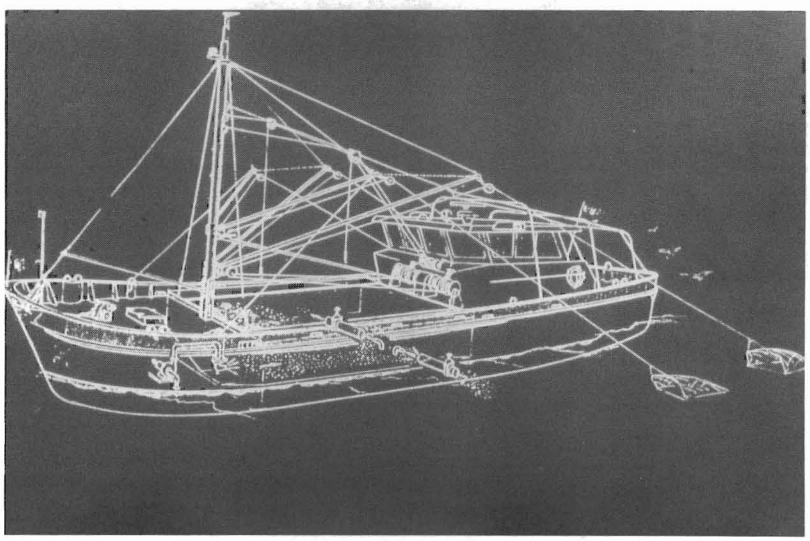

Figure 10
A 1980 generation ship used for dredging and transplanting seed mussels. The mussels are washed out through holes below the waterline.

Figure 11
A ship with full load of mussels ready for unloading. Most ships have their wheelhouses aft.

Figure 12
The mussel auction in Yerseke.

the rest is processed. About 10 processors cook, can, and freeze mussels and cockles, and fabricate a variety of composed mussel and cockle commodities.

The traders and processors market the mussels themselves. The "mussel office" of the Commodity Board for Fish and Fish Products and a cooperative producers' organization of which all growers and traders are members, are responsible for product quality. Quality standards and a minimum price are agreed on before each season. In 1992, these were comprised of a minimum size (35% of the mussels must have a shell length greater than 50 mm), a minimum meat yield of 16%, and an intervention price of DFL0.27 (US$0.14)/kg. Mussels that are landed for auctioning and do not meet these stan-

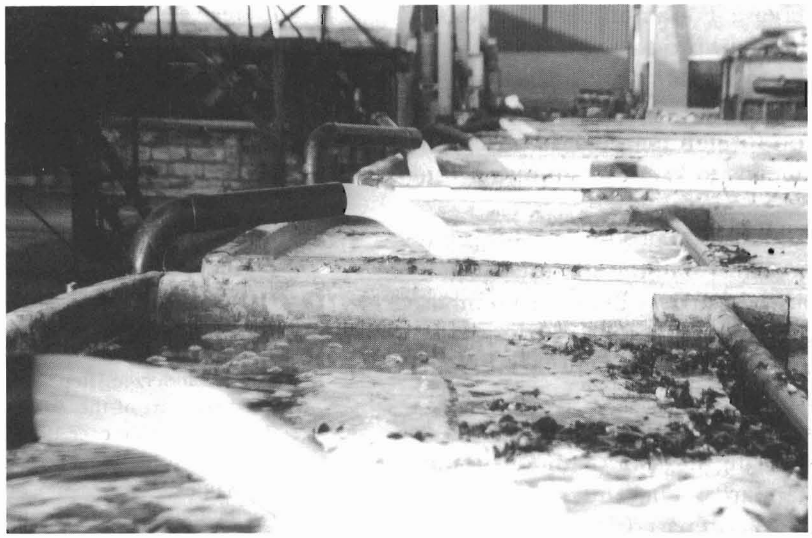

Figure 13
De-sanding containers for mussels at the plant of a mussel processor in Yerseke.

dards are not auctioned but fetch the fixed intervention price, after which they are kept separate on special plots, to be sold back to the growers at the end of the season.

The starting date of the season, which runs from July to April, is collectively agreed upon, mainly depending on market demand. Product promotion, auctioning, the intervention fund for unsold and substandard mussels, and a fund for research are financed with levies paid by growers and traders per ton of product landed or sold. Regulatory tasks, such as supervision of the purity of the product and the water in the production areas, and prevention of introductions of toxic algal species, are delegated by the government to the "Commodity Board," and are eventually controlled by government, which also monitors the national shellfish waters. The industry and the government both pay for the monitoring program.

Between 1991 and 1993, the situation in the mussel industry was dominated by the general lack of mussel seed and market size mussels, a combined result of storm mortality, failing recruitment, and predation by birds. The shortage of mussel seed forced the growers to import about 40,000 t (1.47 million bushels) of mussel seed and half-grown mussels from Germany in 1991–92, for prices between DFL0.80 and 1.20 (US$0.43 and 0.64)/kg. Figure 7 shows how this depressed the profits of growers and how the shortage of market-size mussels raised prices dramatically. In 1991, the auction price reached values between DFL1.50 and 3.00 (US$0.80 and 1.60)/kg and, at the start of the 1992–93 season, even over DFL4.00 (US$2.14)/kg. The average price was between DFL1.00 and 2.00 (US$0.53 and 1.07)/kg. Imports of consumption mussels increased and in 1991–92 amounted to 28,000 t (1.03 million bushels). The high prices on the European market caused increased competition by other mussel exporting countries like Ireland and even Canada and New Zealand. Also, the attractive prices stimulated about seven growers to begin suspended mussel culture, mostly on longlines, that is labor-intensive. Spatfall of mussels and cockles occurred again in 1991 and 1992. A high growth rate of the spat provided reasonable landings again in the 1993–94 season, with prices returning to values between DFL0.8 and 1.5 (US$0.45 and 0.85)/kg.

The Future of Mussel Culture

The mussel and cockle fisheries have grown to a large scale as a result of a high degree of mechanization. This trend, generally in the form of concentration and internalization of the mussel growing, trading, and processing industry, is expected to continue in the coming years. Also, the cockle industry and oyster industry took part in this development. Eventually, this will probably lead to an increase of large, horizontally (all species) and vertically (from primary production to export of commodities) integrated molluscan shellfish firms. A number of specialized family enterprises will, however, be able to maintain themselves.

As the demand for mussels is steadily rising, mussel prices will probably increase. For a number of growers, this will compensate their low productivity. For traders of fresh mussels and the processing industry, however, high prices affect their ability to compete with mussels from other countries on foreign markets. Imports will remain an important means to keep on supplying the export markets.

On 1 January 1993, sanitary and product quality regulations within the European Community were harmonized, and the economical borders between member states disappeared. The microbiological purity of all Dutch mollusk shellfish growing and fishing waters is monitored more intensively and meets the "A" level, which means that no purification is necessary. The equipment of the processing industry is modern and also up to the new standards. The Dutch molluscan shellfish industry feels well-prepared for a new era of free trade and generalized legislation within the European Community.

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Marine Molluscan Production Trends in France: From Fisheries to Aquaculture

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ABSTRACT

The main activity in French shellfishing is culturing. Most culture involves oysters, *Crassostrea gigas*, and *Ostrea edulis*; mussels, *Mytilus edulis* and *M. galloprovincialis*; and to a lesser extent the scallop, *Pecten maximus*, and the exotic Manila clam, *Tapes philippinarum*. Wild species harvested include the whelk, *Buccinum undatum*; abalone, *Haliotis tuberculata*; and bivalves, such as the cockle, *Cerastoderma edule*; pectinids, *Chlamys varia* and *Aequipecten opercularis*; and several clams, e.g., *Mercenaria mercenaria* and *Venerupis rhomboides*. Recreational landings are substantial. The flat oyster, *O. edulis*, has been part of human diets for centuries. Natural beds were exploited through the Middle Ages until the last century by handpicking at low tide and by boat dredging. The effort led to overfishing, and between 1853 and 1859, a repletion program was initiated, mainly based on using wooden spat collectors, which marked the beginning of French oyster culture. In 1860, a shortage of flat oysters led to the introduction of *C. angulata*. Oyster production increased to a record high of 85,000 t of *C. angulata* and 28,000 t of *O. edulis* in 1960, but diseases hit *C. angulata* and led to its disappearance. In 1972, *C. gigas* was introduced, spread rapidly by natural spatfall, and facilitated a fast industry recovery. Oyster production now is 150,000 t of *C. gigas* and 2,000 t of *O. edulis* a year. Oysters often are deployed in ponds for fattening before marketing. *M. edulis* is produced on the Atlantic coast, while *M. galloprovincialis* is mainly produced on the Mediterranean coast. Currently, 1,613 km of bouchots are used to grow mussels, yielding 58,000 t/year; longlines yield 30,000 t; on-bottom culture, 2,000–3,000 t, and the public fishery, 20,000 to 30,000 t. The native clams, *Tapes decussatus* and *T. pullustra* have been harvested. *T. philippinarum* was introduced and hatchery cultured; production peaked at 500 t, but the clam has colonized natural areas. The common scallop, *P. maximus*, and Mediterranean scallop, *P. jacobaeus*, are harvested by dredging. The whelk is fished with pots; landings are about 15,000 t/year. Abalones are harvested by hand at low tide or by diving. Cockle harvests total about 10,00 t/year. The entire shellfishing industry employs more than 20,000 permanent people and 30,000 part-time workers. Most shellfish are marketed fresh in the shell, but some species, e.g., clams and scallops, are marketed frozen.

Introduction

The French consume around 60 species of mollusks, including bivalves, gastropods, and cephalopods. Most mollusks are harvested along the coasts of France, while less than 10 bivalve species are cultured. However, molluscan culture, usually concentrated in highly produc-

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tive estuaries and bays, represents the most important economic activity.

Most molluscan culture concerns oysters (including the introduced Pacific oyster, *Crassostrea gigas*, and the native flat oyster, *Ostrea edulis*); native mussels, *Mytilus edulis* and *Mytilus galloprovincialis*; and, to a lesser extent, the scallop, *Pecten maximus*, and the exotic clam, *Tapes philippinarum*. In addition, French Polynesia is the focus of a highly valuable pearl oyster, *Pinctada margaritifera*, culture.

Mollusks currently are cultivated over 20,000 ha (1 hectare = 0.4 acre): 14,000 ha in estuaries and 6,000 ha in tidal areas, and distributed among 60,140 leasing grounds. *C. gigas* production takes >72% of the total leased grounds. The entire molluscan industry (including mussel culture) employs at least 20,000 permanent and 30,000 part-time people.

Regarding the coastal and intertidal fisheries, most of the species are harvested by boat or at low tide by local fishermen. Although not evaluated, recreational shellfish landings are substantial, particularly on the Atlantic seaside and the English Channel. Species include the squids, *Sepia officinalis* and *Loligo forbesi*; gastropods, particularly the waved whelk, *Buccinum undatum*, and the abalone, *Haliotis tuberculata*; and numerous bivalves such the cockle, *Cerastoderma edule*; the pectinids, *Chlamys varia* and *Aequipecten opercularis*; and several clam species (e.g., *Mercenaria mercenaria* and *Venerupis rhomboides*).

Habitats

France's 5,500 km coastline is divided among three frontages: The north and west on the Atlantic ocean and English Channel totals 3,800 km, and south on the Mediterranean Sea totals 1,700 km (Fig. 1). About 51%

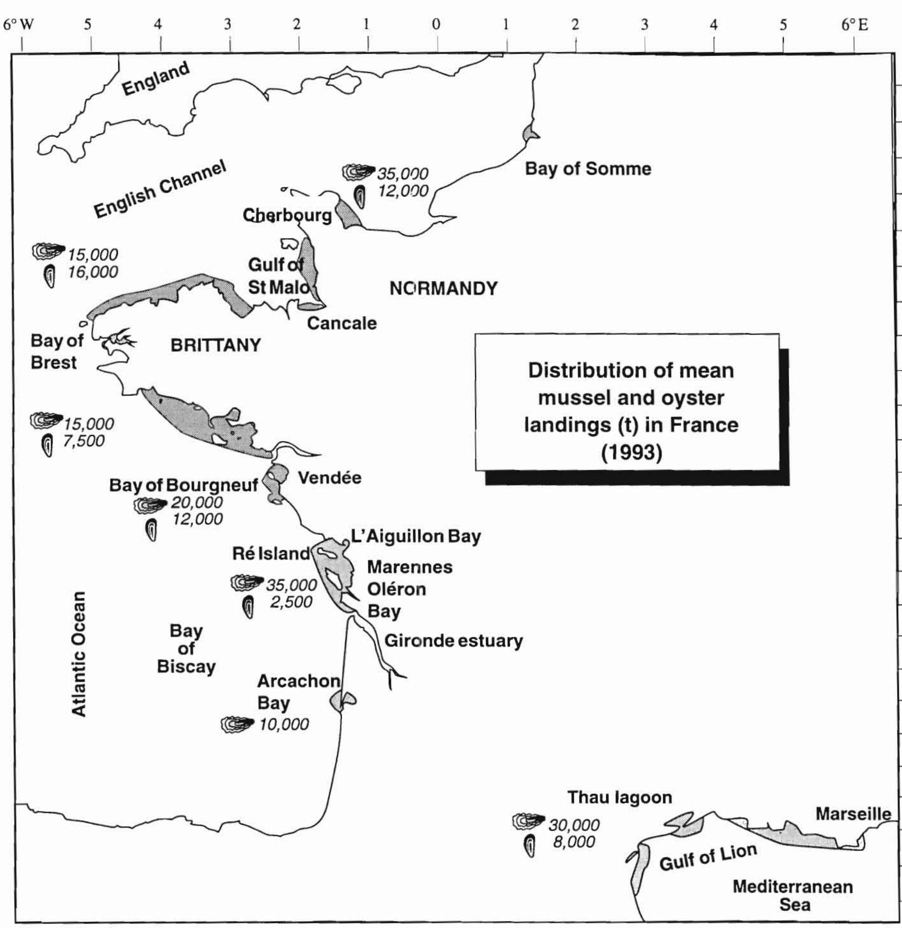


Figure 1
Oyster and mussel culture in France: distribution of the rearing areas with average production (1,000 t) in each area.

of the coasts are urbanized, 960 km intensively so. Of the 5,500 km, 800 km are located in highly productive estuaries, and 580 km are island coastlines.

The coast of France is highly diverse. On the northern and western coast, 30% are rocky shores, 40% are sandy beaches, and 30% are salt marshes, while on the southern part, 65% are mostly rocky shores, 25% are sandy bottoms, and 10% are salt marshes. France's temperate climate is affected by the Gulf Stream, with a biogeographic barrier around Brittany, which limits the spread of northern and southern marine species originating from colder and warmer areas, respectively. In northern Brittany, sea temperatures vary between 6° and 10°C in February and 15° and 17°C in summer, while summer temperatures rise above 20°C on the Atlantic coast. Salinities range from 5‰ in the oyster ponds to 20‰ on the coast in winter to 30 to 35‰ on the coast in summer. Abnormal climatic patterns caused by such variability may drastically affect shellfish population dynamics, affecting local landings (e.g., scallops). In contrast, cultured species may be particularly well adapted to the ecosystem variability, and thus be able to limit abnormal events like recruitment failure (e.g., *C. gigas* spatfall), and result in stabilized production. The main difference between the northern-western and southern frontages is the tide effect, which has determined species diversity and distribution and, therefore, molluscan culture and fishing practices. The English Channel and Atlantic coast are characterized by two cycles a day (i.e., 12 h per cycle), while neap tides alternate with spring tides every week, resulting in highly favorable trophic conditions for molluscan culture. For example, a 15.5 m record high tide range was observed in the Gulf of St. Malo, while averaging 10 m during spring tides. Moreover, the tide varies around 8 m and 4 m on the western part of the northern Brittany and Atlantic sides, respectively. In contrast, tides are almost nonexistent on the French Mediterranean seaside, prompting the farmers to develop subtidal techniques. The salinity in the Mediterranean Sea is about 35‰.

The Oyster Industry

History

The flat oyster, *O. edulis*, a native of Europe, has been part of the human diet for many centuries. The Romans built ponds to stock and sort oysters before exporting them to Rome (Grelon, 1978). Oysters were distributed in shallow bays and estuaries along the French coast.

Natural beds were extensively exploited through the Middle Ages until the last century, by handpicking at low tide or by boat dredging in deeper areas representing a large fishery (e.g., Cancale) (Pichot-Louvet, 1982). Oyster shell piles, reaching 500,000 m^3, equivalent to 5 trillion shells, were observed in the southwest of France near l'Aiguillon and Bourgneuf Bays. Originating from the 10th century, they demonstrate the large oyster fishery activity (Gruet and Prigent, 1986). In the 17th century, oyster culture was initiated using ponds in salt marshes on the Atlantic coast. Oyster spat were collected on rocks and separated from each other after two years, then deployed in oyster ponds for 4–5 more years. Oyster culture increased with a concurrent decline in activity in salt marshes (Héral, 1990). In those early days, oyster spat were obtained only from fishing.

During the 18th century, fishing effort led to overfishing and destruction of natural beds. In 1750, regulations were enforced to restrict fishing during the breeding season (Héral, 1990). In Arcachon Bay and Brittany, several moratoria were enforced for a number of years. During the 19th century, landings became irregular in spite of increased regulations. But an increased demand for fattening young oysters and market demands resulted in boosting fishing effort. From 1857 to 1872, fishing effort on Cancale oyster beds increased by a factor of 13. Moreover, extremely cold winters and predation pressure affected natural spat recruitment. Coste (1861) described Cancale and Arcachon oyster stocks as drastically reduced and those from the Marennes-Oléron areas as totally exhausted.

Between 1853 and 1859, DeBon and Coste initiated a repletion and reseeding program based mainly on using wooden spat collectors similar to those used in Italy. This project marked the beginning of French oyster culture with the control of seed supply. In 1865, Michelet developed the liming tile technique for collecting spat and the oyster box for growing spat in Arcachon Bay (Roche, 1897). But the main change facilitating culture development occurred in 1852, when the French government took over the entire coastal management and established rules of ground exploitation, therefore facilitating rational exploitation (Roche, 1897).

In 1860, a shortage of *O. edulis* seed prompted oyster farmers to import cupped oysters, *Crassotrea angulata*, from Portugal to Arcachon Bay. A natural population settled in the Gironde estuary when a shipment had to be jettisoned during a storm in 1868. This species spread naturally along the Atlantic coast up to Marennes-Oléron in 1874, Ré Island in 1878, then Vendée, and finally to southern Brittany. In spite of this northern limit impeding natural reproduction, oysters were cultured in northern beds (e.g., Cancale) by transplanting seed. Both species then were cultured simultaneously, particularly in Arcachon Bay (Hinard and Lambert, 1928).

Around 1910, oyster production was equally divided between both species (Fig. 2), but then a massive mor-

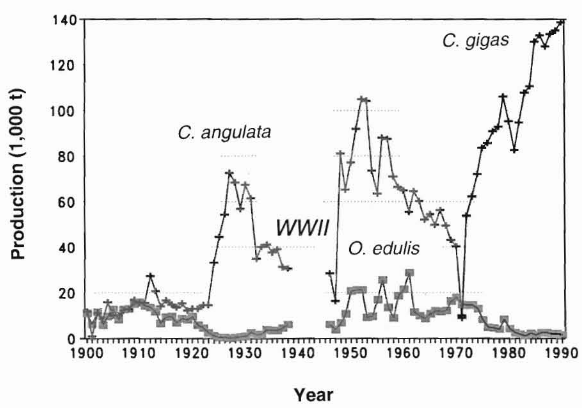


Figure 2
Historical trends in French oyster production, 1900–93.

tality, perhaps caused by a disease, struck the flat oyster, favoring an increase in the culture of the cupped oyster. The flat oyster population later recovered, but only in the southern part of Brittany, with heavy spatfalls in 1925 and 1928. Hinard and Lambert (1928) reported that *C. angulata* had replaced *O. edulis* on the spat collectors in Arcachon Bay.

Spat collecting techniques, meanwhile, became systematic in the southwest of France, using oyster shell strings and slates as well as chestnut and hazel stakes. On the Mediterranean coast, off-bottom culture was initiated around 1900 using *O. edulis* cemented onto steel ropes. Growout facilities were developed in shallow waters (3–4 m) at Seyne and Marseille. Oyster spat came from the Thau Lagoon, but in 1932 this practice was limited to one leasing ground in the lagoon. Oyster production then increased substantially by using spat imported from Brittany. Spat were cemented individually onto poles which were then hung from frameworks deployed over mussel leasing grounds. This species was cultured until 1950–51, when stocks were depleted and replaced by *C. angulata*.

On the Atlantic coast and the English Channel, oyster production increased consistently to a record high of 85,000 metric tons[1] (t) of *C. angulata* and 28,000 t of *O. edulis*, in 1960. Concomitant to the production increase, rearing areas were concentrated in highly favorable sites, usually semiclosed bays protected from storms (e.g., Marennes-Oléron and Arcachon Bays). This resulted in higher stocking densities but poorer growth and increased mortality rates (Héral, 1990; Héral and Deslous-Paoli, 1991). From 1966 to 1969, gill and viral diseases spread over several major rearing areas, leading to massive mortalities between 1970 and 1973, and the final disappearance of *C. angulata*.

[1] At 32 U.S. standard bushels in 1 metric ton.

Seed and adults of the Pacific oyster, *Crassostrea gigas*, were introduced in 1972 to reverse the ailing production and revitalize the oyster industry (Grizel and Héral, 1991). Imports of seed were to sustain farmers' production; imports of adults were to restore natural broodstock beds in several areas along the southwestern Atlantic coast. The introduction was so successful that natural spatfall in the following years in Arcachon and Marennes-Oléron Bays facilitated a fast industry recovery. Then, two diseases, *Marteilia refringens* and *Bonamia ostreae*, spread in the late 1970's and drastically reduced production of *O. edulis* in almost all rearing areas. Despite new management practices and an intensive repletion program, *O. edulis* production has remained low.

Current Status

The annual production of oysters currently supplies the French market and reaches 150,000 t of *C. gigas* and 2,000 t of *O. edulis* (whole weight), with an exchange value of F1,500 million ($254.3 million) and F120 million ($20.34 million), respectively (Fig. 1, 2). Oyster production represents more than 25% of the entire French marine seafood production.

Oyster Culture

Several methods are used to produce oysters, depending on the area. From a biological point of view, *C. gigas*' natural distribution is more restricted than that of *C. angulata*. Natural spatfall occurs regularly on the southwest Atlantic coast, mainly in the Gironde estuary and Arcachon and Marennes-Oléron Bays, affecting the traditional oyster farming practices. Similarly to *C. angulata*, seed transplanting from those bays to Mediterranean oyster culture areas (e.g., Thau Lagoon) and to Brittany and Normandy is done on a large scale. Oyster farmers benefit from dividing their production among several regions.

The seed supply is based mainly on natural spatfall, using artificial spat collectors. The spat supply is reliable and regular. *C. gigas* larvae do not require a specific substrate (assuming it is clean, without fouling and silt) many types of spat collectors are used (Fig. 3, 4). Limed tiles usually are employed in Arcachon Bay and are of particular interest for early spat removal. Plastic PVC tubes with roughened surfaces recently became the favorite, because their weight reduces field labor while maximizing the spat collecting area; automatic equipment facilitates the removal of spat.

Farmers currently are progressively and systematically shifting their spat production from using old spat collectors to PVC tubes. The tubes are immersed in seawater for several weeks, and then sun dried before

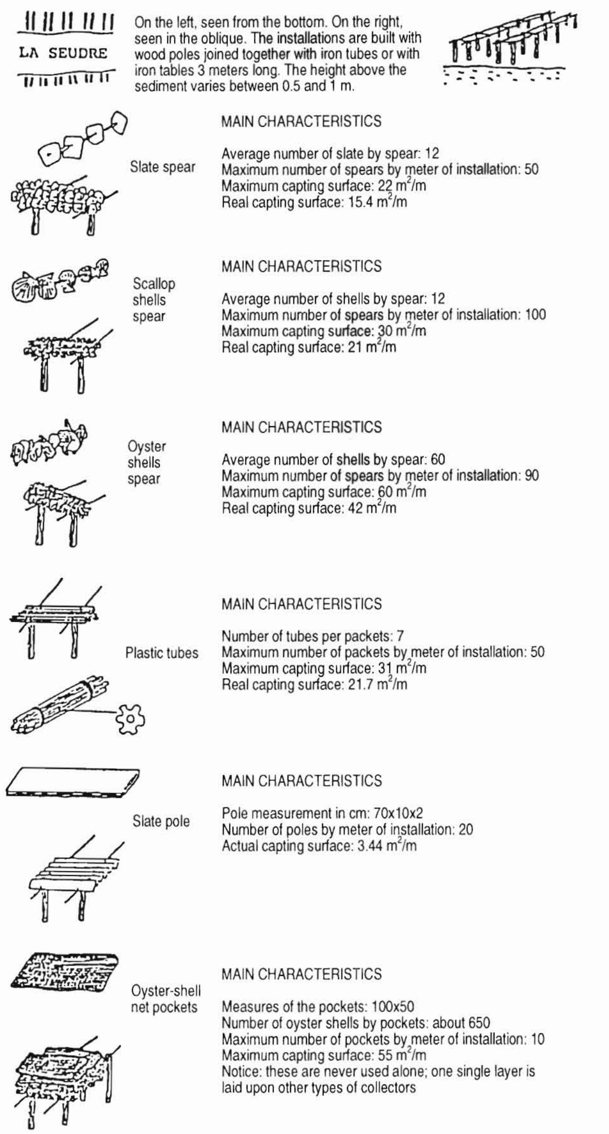


Figure 3
Several types of oyster spat collectors in use and the rack culture in France (from Berthomé et al., 1984).

field deployment, to release any potential hazardous chemicals. Monitoring larval abundance and environmental conditions are the key factors in deploying the spat collectors and maximizing spat recruitment in the two main bays, i.e., Marennes-Oléron and Arcachon. Each year, nearly 5 trillion spat settle in Arcachon Bay on 20 million spat collectors, and 10 trillion spat settle in Marennes Oléron Bay (Berthomé et al., 1984). This technique still is the major one for supplying a reliable and regular seed supply in France and is responsible for the oyster production success.

Hatcheries recently have begun to produce cultchless spat and larvae for remote setting techniques. The latter is of particular interest to oyster farmers located far from natural spatfall areas (e.g., Normandy). The choice of spat collector for *O. edulis* settlement is more specific, and usually is tiles coated with lime and sand. The lime composition varies among breeding areas (Marteil, 1976). Spat are removed after 6–10 months. More recently, use of tubular nets filled with mussel shell and deployed off-bottom has been proven more cost-effective than tiles in southern Brittany (Grizel et al., 1979).

Several techniques are used for the pregrowing and growing stages, depending on peculiarities of each rearing area. The duration of each stage depends on local stocking densities and ecosystem carrying capacity. Oysters are produced using on-bottom and off-bottom techniques, as well as in subtidal or intertidal leasing grounds. On-bottom culture, intertidally or in deep water, is carried out by first hardening the bottom and then sowing seed directly with or without their spat collectors. In intertidal areas, a plastic fence defines the rearing area and effectively reduces green crab, *Carcinus maenas*, predation. Following 1–2 years of pregrowing, spat are scraped from the cultch, sorted by weight, and then put back on the bottoms for further growth.

The mean density for *C. gigas* is 5 and 7 kg/m^2 during the pregrowing and growing stages, respectively (Bacher, 1984). Marteil (1976) reported *O. edulis* densities ranging from 0.5 kg/m^2 the first year, 1 kg/m^2 the second year, and 3–5 kg/m^2 the third and four years.

On-bottom culture requires oyster farmers to harrow or fork the oyster beds to limit siltation. One ton of *C. gigas* and *O. edulis* spat yields 20 t and 12–15 t (whole weight) of marketable oysters, respectively. In subtidal areas in southern Brittany, the density of *O. edulis* has been reduced from 0.5 to 0.1 kg/m^2 to maximize the growth rate since bonamia disease drastically reduces the survival rate of the 3- to 4-year-old oysters. Disease effects also prompted several oyster farmers to switch to *C. gigas* culture in subtidal and intertidal rearing areas. Subtidal culture is considered as more cost-effective than intertidal culture, but requires higher investment. The availability of grounds, however, has not as yet been assessed.

Rack culture on iron tables currently is the most common technique used in intertidal areas on the Atlantic coast and English Channel (Fig. 3). Spat collectors or oyster bags are attached to tables 3 m long and located at 0.5 m off-bottom. From 50 to 100 collectors/m is the usual initial density; it is decreased to 8–10/m a year later. After removal from the collectors, the seed is sorted and deployed in bags that are 1 m long and 0.5 m wide and whose mesh size depends on the oyster size. Although more efficient than on-bottom culture, this method can lead to overcrowding of oysters in bags and siltation underneath the tables by biodeposition. It there-

Figure 4
Detail of iron pipe spat collector covered with 8-month-old oysters, *Crassostrea gigas*.

fore requires stricter management regulations. Oyster bags weigh around 5 kg initially and 15–20 kg when the oysters reach commercial size (Bacher, 1984). Rows of tables, 30–100 m long, are placed parallel to each other, depending on the tidal current pattern and direction (Fig. 5).

At the end of the rearing cycle on the Atlantic coast, oysters are often deployed in oyster ponds for fattening (Fig. 6). Old salt marshes were converted specifically to ponds for oyster culture. Oysters are deployed at low density ($<10/m^2$) in the shallow (0.4 m) earthen ponds which are filled by gravity with seawater at high tide. During 10 days of neap tide, no water exchange occurs, and the phytoplankton blooms since the turbidity is low and the nutrient load is high.

The phytoplanktonic species, *Haslea* (*Navicula*) *ostrearia*, is of particular interest. Following this species' bloom, its green pigment diffusing in the water is absorbed by oyster gills. This process leads to green colored oysters which are particularly tasty and expensive in the market. Two brands are defined, "fines de claires" for oysters spending a month in the oyster ponds at a density of $20/m^2$, and "speciales de claire," for oysters fattened 2 months at a stocking density of $10/m^2$.

Farmers in Marennes-Oléron Bay have developed a special quality brand called "Label Rouge," which has stricter definitions than the previous ones and is based on a 17 June 1983 State Decree (Ministry of Agriculture). This brand requires the fulfillment of high standards for oysters (e.g., shape, >9% meat condition index, salinity >20ppt, color, size), rearing conditions (such as a $20/m^2$ density), at least a month in oyster ponds for fattening, tasting standards, as well as packaging and conditioning (e.g., storage temperature). The oysters should be consumed within 10 days after being packaged. This brand is a consumer guarantee for a top-rated quality product. About 25% of the French production is marketed as "fines de claires," while the "speciales de claires" and "label rouge" (red label) oysters together constitute <10% of the yearly production.

In the Mediterranean lagoons, where the tidal range is less than 1 m and the depth around 10 m, permanent growout facilities are deployed from the sea surface. The structures are 50 m long and 10–12 m wide and support about 1,000 suspensions (Hamon and Tournier, 1981). Spat collectors covered by spat coming from the Atlantic coast are hung directly under the structures; the oysters are marketed 12–18 months later. Some of the oysters are cemented individually on wooden poles and hung for one additional year to yield large fat oysters aimed at a special market (Raimbault, 1984). The average yield is 5–7 t of oysters per structure.

The Public Fishery

Fishermen harvest oysters on natural beds on the Atlantic coast every year. The beds resulted from the building of oyster bars for broodstock in the 1970's. A quota,

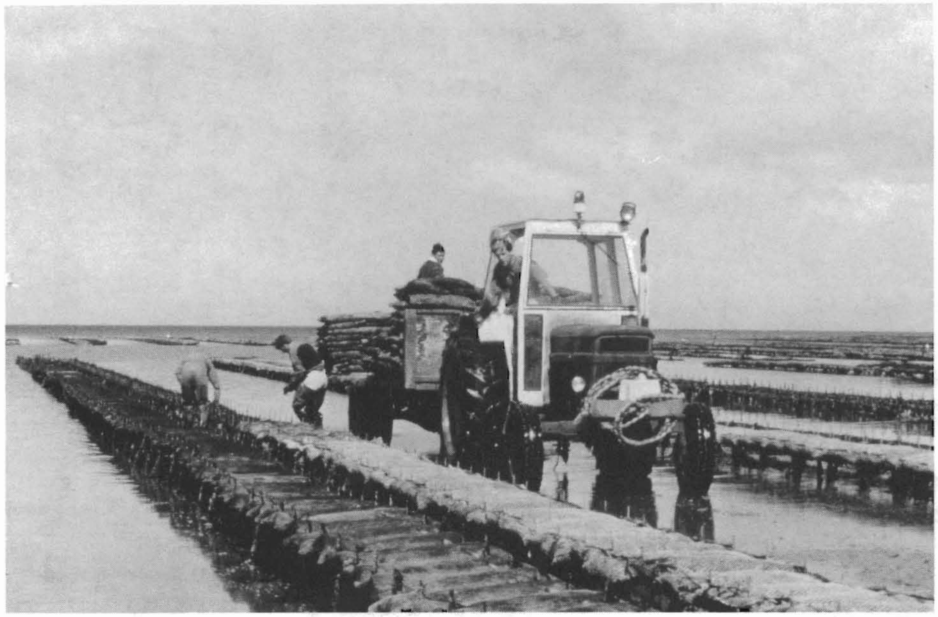


Figure 5
Harvesting oysters, *Crassostrea gigas*, grown in bags off-bottom on iron tables.

based on a yearly stock assessment, is given to authorized licensees for harvesting oysters in bacteriologically polluted areas. Landings have to be declared to the Administration, and the oysters are grown in certified areas for at least 6 months before marketing. In unpolluted areas, the public fishery is totally open during a specified harvesting season. This public fishery aims to keep a sustainable wild broodstock similar to a reserve system and to limit oyster proliferation that may interfere with culture. However, the "natural" spatfall relies mostly on the large cultured stock (e.g., >120,000 t in Marennes-Oléron Bay on 3,200 leased hectares) rather than on the wild stock (e.g., 22,000 t) (Prou et al., 1994).

Regarding *O. edulis*, a moratorium was enforced early in the century on dredging the natural beds of Cancale and the western coast of Normandy that once yielded 10,000–15,000 t yearly. Although a slight rebound occurred in 1970 with 1,600 t, landings have declined steadily to the present time with 10–20 t during the harvesting season in November 1993.

Harvesting Methods

In intertidal areas, harvesting usually is carried out manually. Oysters from bottom culture are harvested using oyster forks, stored in baskets, and then loaded onto flat boats. Around 1.5 t is harvested by each farmer during one low tide. New vehicles are being tested for culturing and harvesting oysters on hard bottoms (Fig. 7). Although not mechanized, harvesting oyster bags is an easier task and yields twice as much weight as before (i.e., 200 bags during one low-tide period) (Fig. 5). Experiments currently are in progress to mechanize this process. In the Normandy area, tractors currently are in use instead of flatboats to work on oyster fields, since the tidal range is >10 m, the intertidal area is large (e.g., several km), and the bottom is hard. In subtidal areas, dredging boats commonly are used; each harvests about 15 t/day (Marteil, 1976).

Processing and Marketing

Once harvested, oysters are brought to a processing plant where they are washed with automatic equipment and sorted by weight manually or mechanically (Fig. 8). Electronic computerized equipment recently has been developed to sort at least 8.5 t/day in up to 8 oyster-weight sizes. Oysters then are packed and marketed.

In France, oysters are sold on the fresh market without shucking, therefore explaining cultural and marketing practices. Oysters usually are eaten raw but a small market involving restaurants requires large oysters for cooking and stuffing. Half of the production is marketed for Christmas and for New Year's Eve, requiring a well organized marketing system. Oyster farmers sell about 20% of their production directly to local

Figure 6
Aerial view of oyster ponds or claires.

markets (SECODIP, 1983) (Fig. 9). Supermarkets have been increasing their market share, which currently is estimated at about 30%. Few oysters are imported or exported since the French supply and demand is balanced. Prices average F10 or $1.69/kg, but they fluctuate widely and depend on product quality and stock availability. Extensive trade occurs between the various rearing areas; they are characterized by a large variation in operating costs.

The Mother of Pearl and Pearl Oyster Industries

History

During the 19th and early 20th centuries, the black-lipped pearl oyster, *Pinctada margaritifera* (L.) var. *cumingui,* was harvested for mother of pearl shell and used for button manufacture as well as the fancy goods industry (Intes, 1982; Coeroli, 1985). This species is distributed among five archipelagos in French Polynesia including Tuamotu and Gambier. This fishery began in 1802 at Gambier archipelagos and reached a yearly production of about 500 t from 1889 to 1940. Fishermen dove to depths of 20–30 m and tore away pearl oysters from coral pinnacles.

The first regulations to protect the resource, enacted in 1904, sought to limit fishing effort. Lagoons were spatially divided into three parts and opened for fishing one after another. Despite the regulations, a record high production was reached in 1919 with 1,000 t and later 1,924 t in 1928. From 1940 to 1960, the average yearly landings declined to 700 t, demonstrating the fishery decline despite additional 1954 regulations limiting fishing effort (i.e., quotas and broodstock sanctuaries). Since then, consistent overfishing led to shrinking landings and a 50 t record low. For example, the landings in the Takapoto Lagoon declined from 400 t to less than 10 t in 1984.

From 1962 to 1964, pearl culture was successfully tested, with 1,095 black pearls being produced. Since 1972, pearl oysters have been harvested mainly to supply the pearl culture industry.

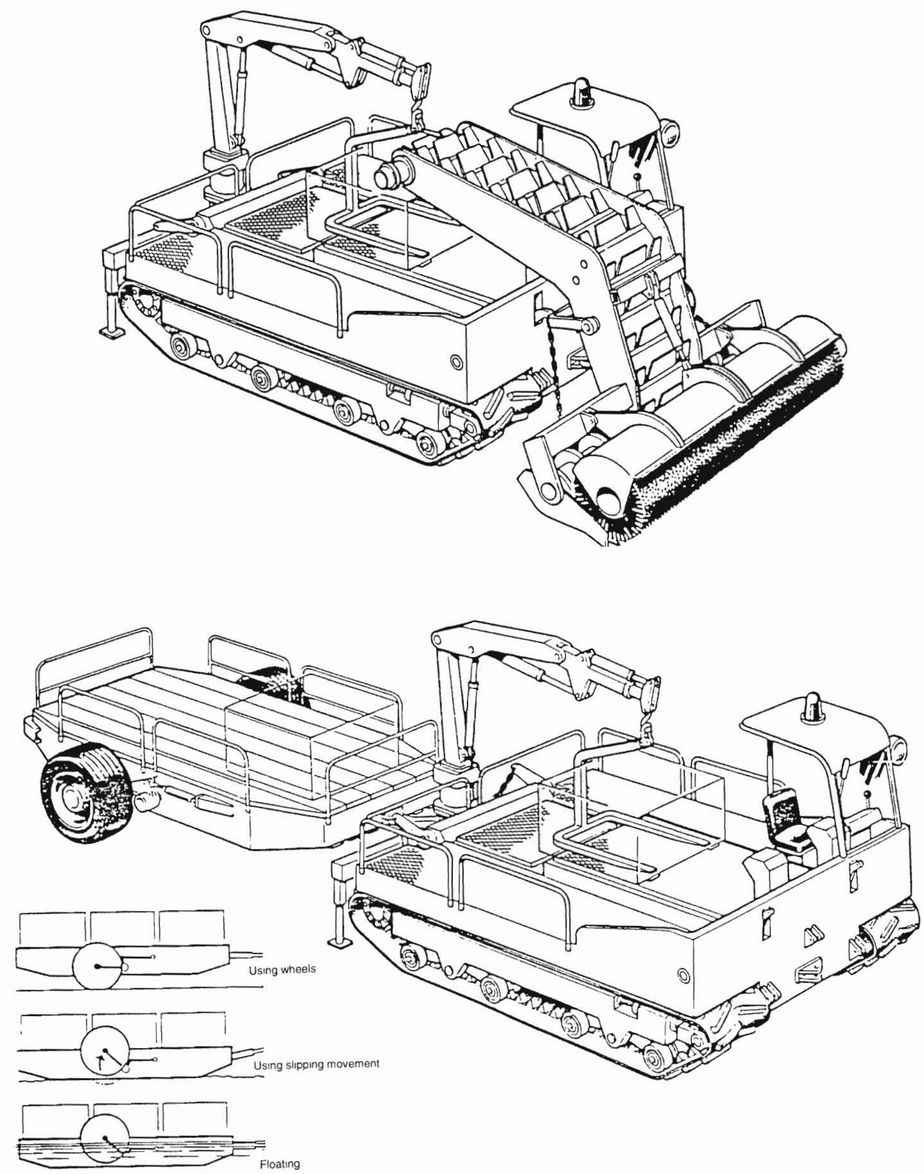


Figure 7
Recent shellfish culture equipment. Top figure shows oyster (on-bottom) harvesting machine. Bottom figure shows this machine geared with a trailer which can float or be used on soft bottom (slipping movement) and on hard bottom (wheels) (from Priour, 1986).

The first trials of mother of pearl culture were made in 1875; spat were collected in the Tuamotu and Gambier archipelagos (Coeroli, 1985). Unfortunately, the most common species collected, *Pinctada maculata*, had limited commercial value. The spat collecting method, technically under control by 1976, resulted in boosting pearl oyster culture; it was carried out by family businesses and cooperatives. About 80% of spat currently is obtained by using spat collectors, while the remainder is from collections on natural beds. Pearl culture is one of the most important industries in French Polynesia (Coeroli, 1985, Coeroli et al., 1984, Buestel et al., 1993). As early as 1976, the American Institute of Gemology (GIA) officially recognized the Tahiti pearl as "Cultured pearl of natural color." Later on, the International Confederation of Jewelery (CIBJHO) recognized the label of "Pearl from Tahiti."

Figure 8
Sorting equipment for grading oysters by weight. The equipment consists of a rotating turret with calibrated counterweights.

Current Status

Pearl culture currently ranks third behind oyster and mussel culture in commercial value. In 1976, the first black pearl exports weighed 6 kg, worth $82,000. In 1983, production reached 139 kg, worth $4,182,000 (Coeroli, 1985). Since 1980, exports of black pearls have increased by a factor of 40, and 600,000 black pearls were exported in 1992, yielding F234 million ($39.66 million) (Buestel[2]).

Culture

Pearl oyster culture is based on a 4-year rearing cycle including spat gathering (12 months), rearing (18 months), and then grafting and harvesting (18 months). Spatial management of cultured areas is similar to that currently used in culturing oysters on leased grounds in the mainland of France. Spat collectors are hung 3–10 m deep from anchored buoys. They are deployed regularly throughout the year since settlement may occur year-round. However, two settlement peaks occur: from July to August and from October to December (Coeroli, 1985; Buestel et al., 1993). Polyethylene strips and branches of trees commonly are used as spat collectors.

One year after settlement, the oysters, 6–10 cm long, are removed from the spat collectors. Each collector yields up to 50 spat. In 1985, Takapoto Island alone produced 500,000 spat in 1985. Oysters then are heel pierced, attached to strings at a density of 10 oysters per unit, and then deployed on subsurface long-lines at a 7–10 m depth range. The growout facilities are protected from fish predators (*Tetrodon* sp. and *Balistoides* sp.) with wire netting. Every 3 months, fouling organisms are removed from the oysters. Once they attain adult size, 11 cm long, the oysters are grafted by introducing into their gonads a piece of young oyster mantle (2x2 mm size) and a nucleus (6–8 mm) originating from the freshwater bivalve, *Pleurobema cordatum*. Commercial pearls are obtained in 15% of the grafted oysters 18 months later. But top-rated pearls usually are limited in number. Oysters used to be sacrificed when pearls were removed, but now a second grafting is being tested.

Marketing

Since the pearl culture industry began recently in French Polynesia, marketing of the pearls is only partly organized. Market instability has resulted from the boosting of supply and the limited professional structure in the face of well organized traders. Japanese companies control 85% of the market.

The Mussel Industry

History

Mussel production in France involves two common species, i.e., *Mytilus edulis*, which is widely distributed along the English Channel to the southwest coast of France, and *Mytilus galloprovincialis*, which is distributed mainly on Mediterranean shores. Genetic crosses of the two species are also present in several locations along the French coast (Coustau, 1991). This wide distribution has favored extensive fishing activity through the centuries, until the 19th century. However, as early as 1681, a

[2] D. Buestel, IFREMER, Tahiti Center, Vairao, French Polynesia, 1993. Personal commun.

Figure 9
Direct marketing of oysters by farmers at a small market.

royal decree was enacted to control the public mussel fishery in the Cancale area. At that time, several natural beds were already described as overfished, well before the oyster beds were overharvested (Pichot-Louvet, 1982).

Several natural beds along the French coast were reported as exhausted in 1933, but fishing effort was still high in the remaining productive areas (Lambert, 1933). Explanations for the decline included overfishing, dredging effects, recruitment variability, and destruction of the juveniles during fishing. Mussel populations meanwhile colonized ancient overfished oyster beds in several places, particularly around Noirmoutier which became an intensively fished area.

Mussel culture methods were developed as early as the 13th century, but only in L'Aiguillon Bay in southwestern France (Dardignac-Corbeil, 1979). A historical sketch describes the development of the wooden pole or "bouchot" culture by a shipwrecked sailor in 1235. While using nets to catch birds in the intertidal area of the Bay of L'Aiguillon, he noted that mussels settled on the poles and yielded a better product than did wild mussels. He then started mussel culture using wooden poles sunk in muddy bottoms. The wooden poles were deployed into two merging lines, 200–300 m long, with a 45° V shape. The poles were linked to each other with boughs. The resulting growout facility was also used as a local finfish (pound) net. A net was deployed at the V head to catch finfish at ebb tide. However, space was not rationally used by this technique, which also maximized siltation.

Following an 1852 State Decree regarding government management, laws were enacted in 1853 and 1859 forbidding the V-shaped bouchot. After that, the two lines of poles were set parallel to each other and deployed perpendicularly to the coast. This technique spread widely along the French coast during the late 1800's. In 1855, L'Aiguillon Bay was still the only area using the "bouchot" technique (Coste, 1861), but the rearing area extended quickly northward with concomitant production increases and later (1860) to the La Rochelle and Marennes-Oléron areas. More recently, the rearing areas were extended to northern Brittany (1954) and the western coast of Normandy (1965). At the turn of the century, bottom culture was developed where bouchot culture failed, for example in Le Croisic and Isigny (Lambert, 1934).

Current Status

Currently, 1,613 km of bouchots are distributed along the French coast. They yield 58,000 t[3] a year (Fig. 1, 10). Bottom culture is located mainly in the Bay of Brest, and annual harvests run from 2,000 to 3,000 t (FIOM, 1982). Harvests from longline culture were 30,000 t in 1993 (CNC, 1993). Annual landings from the public fishery show a large variability resulting from

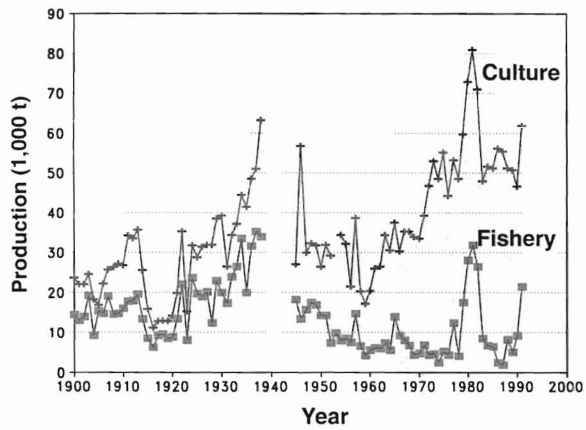


Figure 10
Historical trends of French mussel production (1,000 t), including culture and wild fishery, 1900–90.

irregular spat recruitment and usually range between 20,000 and 30,000 t. The main natural beds are located in Normandy and yielded 25,000 t on 1,000 ha in 1980 and a record high of 50,000 t in 1993. The overall production represents an exchange value reaching F650 million ($110.2 million).

Mussel Culture

Bouchot Culture—The bouchot culture technique has not changed drastically since its origin. Each pole is 4–7 m long, 15–25 cm diameter, and protrudes 2–3 m above the bed. Several wood types currently are used including pine, oak, and more recently, squared Brazilian hardwood. The bouchot structure depends on the rearing area. In southwest France, the structures are 50–60 m long with 120–129 poles in single or double lines for spat settlement and 80–90 poles for growing (Dardignac-Corbeil, 1990). Bouchots should also be spaced at least 25 m apart. In northern Brittany, bouchots are 100 m long, with 130–180 poles, and in Normandy they have <200–250 poles. Bouchots are deployed during the first trimester, and those for spat gathering, 3 months before settlement.

In the spring (May–June), spat settlement occurs intensively in several locations in southwestern France. The spat are sold to mussel farmers in the remaining rearing areas where this activity is not cost-effective (e.g., northern Brittany and Normandy). Spat are gathered by using wooden poles set in the deepest areas or horizontal coconut fiber ropes strung on the poles just before settlement (Fig. 11). The structures remain in place until July. Seed from the poles then is transferred

Figure 11
Spat-collecting ropes (coconut fibers) covered with blue mussel, *Mytilus edulis*, seed.

to tubular nets that are reattached around the growing poles (Fig. 12). Mesh size depends on mussel size. The mesh tubes (3–5 m long) are placed around the poles and nailed at each end. Through August, the mussel seed spread and eventually cover the entire pole. Each pole produces between 25 and 60 kg live weight of mussels per rearing cycle (Boromthanarat and Deslous-Paoli, 1988; Gerla, 1993).

On Bottom—On-bottom culturing is based on transferring mussels from natural beds with high densities to culture plots where the density is reduced to improve growth and fattening, and to control predation. On-bottom culture is located mostly in the Boulogne area, Bay of Brest, and southern Brittany. One-year-old mussels usually are dredged in the Bay of Bourgneuf (Noirmoutier) and the Loire estuary, then taken to the culture plots where they are deployed at densities ranging from 25 to 30 t/ha. This process is carried out in spring and early summer. The rearing cycle lasts 14–24 months.

Figure 12
"Bouchot" mussel culture: Deployment of socks filled with blue mussel, *Mytilus edulis*, seed on wooden poles.

Longline Culture and Suspended Culture—In the Thau lagoon, off-bottom culture is based on fixed suspended structures similar to those used for oyster culture. Mussel reproduction occurs almost year-round, but is most intense during fall and winter. Seed is transplanted in plastic mesh tubes and hung vertically from fixed tables.

On the Atlantic coast, a reduced availability of intertidal areas for developing mussel culture led to the development of longline methods. The first trials were conducted in Pertuis Breton using raft techniques during the 1960's (Dardignac-Corbeil, 1990). New subsurface longlines recently have been developed to resist storm and wave effects along the Atlantic coast and offshore along the Mediterranean seaside (i.e., Languedoc Roussillon region) (Barnabé, 1990) (Fig. 13). Several longlines are particularly adapted to areas showing high tidal cycles on the Atlantic coast. Floats are connected together by horizontal lines that support a large number of vertical ropes where mussels are grown. Production rates reach 18–20 t/ha/year.

The Public Fishery

In the Normandy area, around 100 fishermen working on 40 boats are licensed in the public fishery, while in the Bay of Bourgneuf, around 20 fishermen are so licensed. Boat sizes run between 12 and 16 m. The fishermen also harvest scallops, lobsters, and coastal finfish. The decline of the finfisheries prompted additional entries and increased effort in the mussel fishery. In the early days (19th century), natural beds were harvested once every 3 years (Lambert, 1933), but now fishing is done every year and all year long except February, when the quality of mussel meat is reduced by spawning. (Earlier, fishing was allowed only from June to the following February.) A fishing quota now allows 500 kg of mussels/day/fisherman. No fishing activity is authorized during weekends, holidays, or nights.

Harvesting Methods

Harvesting begins as soon as the mussels reach the 40 mm marketable length after a 12–15 month rearing period. A 60–80 mm length is most common. Several techniques are used depending on areas and cultural practices. Mussels grown on wooden poles (bouchots) are harvested by hand or more often by using hydraulic fishing equipment that removes all the mussels at once (Fig. 14). A cylinder is lowered to the bottom of the pole, closed, pulled up, and the mussels are dumped onto a trailer or into containers on boats. Amphibious vehicles currently are used in intertidal areas to maximize working time. Hydraulic forks are also used for unloading.

Mussels are harvested from on-bottom culture plots and public beds by dredging with boats of 7–16 m length and engines of 40–300 hp. In unpolluted areas, mussels are dredged, cleaned, and sorted by size directly on the decks of the boats. Legal-sized mussels are packed in 25 kg bags. Undersized mussels are thrown back on the beds. In contrast, harvesting with longlines requires especially designed vessels that are 10–15 m long and are equipped with heavy lifting gear.

Processing and Marketing

In processing plants, automatic equipment facilitates washing, declumping, debyssing, and grading. Marketable mussels are packed in 15–25 kg bags and sold for the fresh market. Undersized mussels are transferred to mesh tubes that are reattached in the field around the growing poles.

Marketing is based on species peculiarities. Since *M. edulis* spawn in spring, their condition index and the

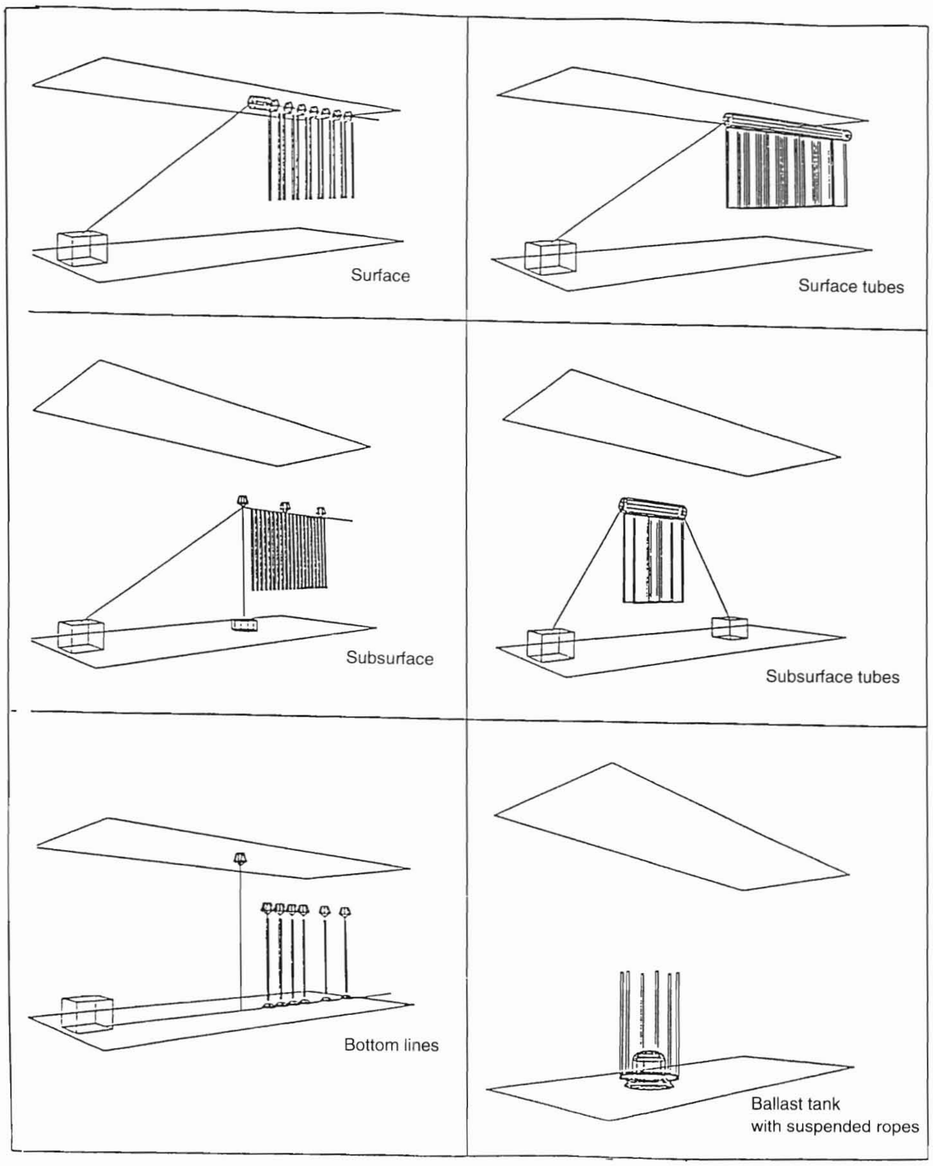


Figure 13

Various types of longline techniques: surface, subsurface, bottom lines, surface, subsurface tubes, and ballast tank with suspended ropes (from Müller et al., 1987, IFREMER/DITI, cited in Héral and Deslous-Paoli, 1991).

meat quality are low between March and May, facilitating the marketing of *M. galloprovincialis*. The commercial season for mussels harvested on the Atlantic coast and along the English Channel lasts from June to November-December. Mediterranean production is commercialized all year since no major seasonal spawning event occurs. Imports, mostly from Holland, fulfill the French demand from September to March-April of the following year. Prices for the "bouchot" mussels average F7–8 ($1.19–1.36)/kg, but fluctuate widely and depend on product quality and stock availability. In contrast, the ex-vessel value for mussels harvested on public beds peaks at F2–3 ($0.34–0.51)/kg and depends exclusively on stock availability.

The Clam Industry

History

The native clams *Tapes decussatus* and, to a lesser extent, *Tapes pullastra* have been fished extensively along

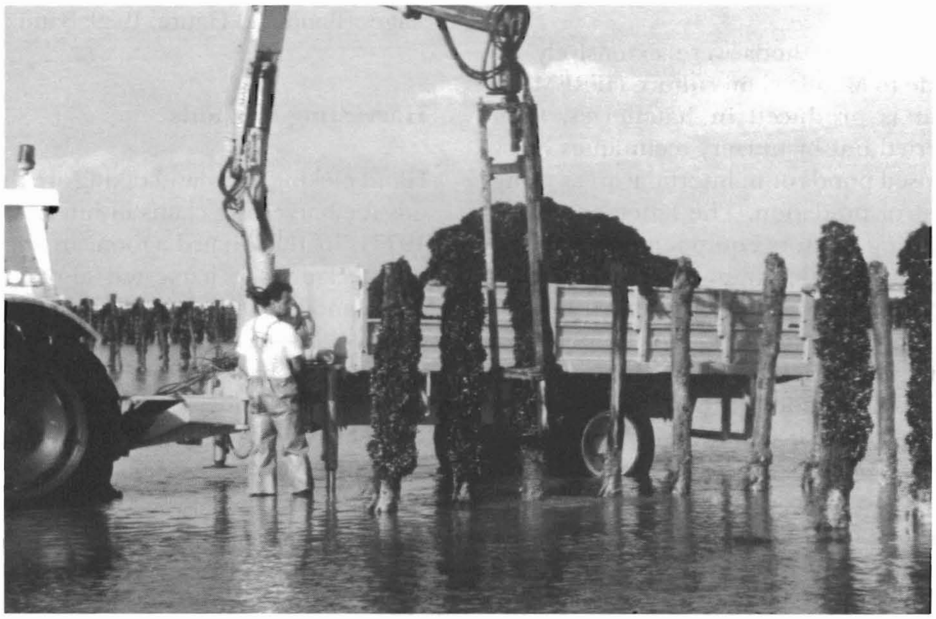


Figure 14
Hydraulic harvesting gear scraping mussels from bouchots (wooden poles).

the Atlantic coast and in Mediterranean lagoons (Vilela, 1950; Partridge, 1977). Guérin and Ganivet (1907) reported the distribution of natural beds along the French coast. Brittany and the Thau Lagoon were the main productive areas, but overfishing and irregular landings, leading to extensive imports, prompted shellfish farmers and scientists to develop clam culture.

The first experiments were based on transfers of natural spat to culture plots in Rouqueyrol in 1863, then in 1878 in the Gulf of Gien and Bay of Toulon (Mediterranean), where a broodstock sanctuary was established (LeVaillant, 1953). Trials in southern Brittany early in the century similarly relied on erratic natural spat supplies (Nicol, 1910, cited in LeVaillant, 1953). In 1955, 750 leasing grounds, mostly in southern Brittany, were seeded with clam spat (LeVaillant, 1953).

More recently, hatchery techniques provided a basis for extensive culture development by controlling the reproduction cycle. In 1972, the commercial hatchery SATMAR experimented with the Manila clam, *Tapes philippinarum*, and introduced a broodstock of 150 individuals from Seattle, Wash., to develop breeding techniques. On the basis of growth and survival rate comparisons, the Manila clam was selected for culture (Latrouite and Perodou, 1979). Early in 1980, spat production was under control in hatcheries and was sufficient to sustain a large clam production.

In 1985, clam culture practices were fully operational in several ecosystems, including tidal and intertidal areas and oyster ponds, and were proposed as a way to diversify oyster as well as mussel culture. However, in 1986, an abnormal shell calcification called "brown ring," resulting from a viral infection (Paillard and Maes, 1994), appeared in the clams in several rearing areas and reduced the landings (Goulletquer et al., 1989). Later on, in 1987 and 1988, this species extensively colonized natural beds in southern Brittany, leading to a new public fishery 2 years later. Annual production ranged from 1,000–1,500 t (whole weight) (Bachelet et al., 1993). Landings of cultured clams peaked at 500 t. Since then, large landings by the public fishery has drastically slowed the development of clam culture.

Current Status

In 1993, clam culture yielded 1,000 t distributed among Normandy (50 t), southwest Atlantic (200 t), and Brittany (700 t)[4]. Half of the production in Brittany is based on a rearing cycle including natural spat gathering and deployment in culture plots. Public beds yield around 3,000 t/year with two-thirds coming from the Gulf of Morbihan (1,000 t of *Tapes philippinarum*) and the Thau Lagoon (1,000 t of *T. decussatus* and *T. pullastra*).

[4] At 26 U.S. standard bushels in 1 metric ton.

Clam Culture

Cultural practices and methods were extensively reported in the guide to Manila clam culture (IFREMER, 1988). Clam spat is produced in hatcheries, then pregrowing is carried out by nursery techniques or by seeding in semiclosed ponds or in intertidal areas using mesh nets to control predation. The latter process is fully automated, using tractors equipped with specific gear to seed the clams and deploy mesh screening over them. Additional gear allows automatic net brushing to control fouling. Grow-out facilities also include protected culture plots and semiclosed ponds. In the ponds, clams are grown in the bottom with mesh nets placed over them; appropriate mesh sizes are used with different sizes of clams (Goulletquer et al., 1988; DeValence and Peyre, 1989). The usual rearing density in intertidal culture areas is about 250 clams/m^2.

More recently, new intensive techniques were developed to counteract a food limitation that occurs in semiclosed ponds in summer. Farm fertilizer and mineral nutrients are used on an experimental scale to maximize primary production (Hussenot et al., 1992). A recent discovery of underground fossil seawater in several locations along the Atlantic coast facilitates mass production of microalgae (Baud, 1988). Standard conditions for intensive rearing (i.e., >2kg/m^2) of Manila clams were established successfully in the nursery and growing stages (Baud and Haure, 1989; Baud and Bacher, 1990).

Harvesting Methods

Hand picking and hand raking are the traditional methods for harvesting clams in intertidal areas (Partridge, 1977). In the Thau Lagoon, in shallow waters <10 m deep, clams are harvested also by skin divers using forks, and by fishermen using hand rakes from boats. For clam culture to be cost-effective, it was essential to have mechanized harvesting techniques. In intertidal areas, harrowing machines and specially-equipped tractors harvest 300 and 600 kg of clams per hour, respectively (Fig. 15, 16). A dredge was specifically developed to harvest clams in semiclosed ponds (DeValence and Peyre, 1989).

Processing and Marketing

In the processing plants, automatic sorting machines facilitate washing and size grading. Clams are marketed mostly for the fresh market; the larger ones are sold to restaurants. Clam prices have decreased from F60 or \$10.17/kg (30 clams/kg) in 1983 to F50 or \$8.47/kg in 1987, and to F30 or \$5.08/kg in 1993, because the

Figure 15
Motorized equipment for harvesting cultured clams in soft bottom and small-acreage leases.

Figure 16
Harvesting equipment for cultured clams in intertidal hard-bottom areas.

supply has been increasing from the public fisheries in France and Italy.

The Scallop Industry

History

The common scallop, *Pecten maximus*, and the great Mediterranean scallop, *P. jacobaeus*, distributed in the English Channel and Atlantic Ocean, and Mediterranean Sea, respectively, are the most common scallop species harvested in France. Scallops used to be more extensively distributed in shallow bays and estuaries along the French coast. They were distributed near the natural oyster beds and represented a bycatch of the oyster dredging fishery (LeDantec, 1947). Fleets of small vessels designed for coastal fisheries originated from this commercial activity and dredged for scallops in winter in the relatively protected bays.

Irregular recruitment and overfishing resulted in cyclic production in several areas. At the turn of the 20th century and concomitant with railway development, the size of the dredging fleet was increasing in Normandy to supply fresh markets. But in 1906, a survey of shellfish beds described the scallop populations as overfished in this region. In 1927, a fishery rebound occurred, and 200 fishing boats dredged the beds. In 1935, the resource disappeared again (CNEXO, 1977). Before 1960, the main productive areas were located on the Atlantic coast in southern Brittany (i.e., Yeu Island) and the Bay of Brest, where production peaked at 35–45% of the total French landings (Rieucau, 1980). Scallops were marketed canned or fresh.

The cold winter in 1963, combined with overfishing during the previous years, affected the entire scallop population. Scallops in the Bay of Brest disappeared, but those in northern Brittany (e.g., St. Brieuc) were discovered following the decline of the fishery for the venerid, *Venus verrucosa*.

Fishing effort, meanwhile, increased in the eastern part of the English Channel. Landings increased progressively from 5,000–6,000 t (whole weight)[5] in 1963 to 20,000 t in 1972. Eastern Channel areas yielded 48% of the total catch; 46% were harvested in northern Brittany, mostly from St. Brieuc; and the remaining 6% came from the Bay of Brest and southern Brittany. Since a record high of 25,000 t during the 1970's, the scallop fishery has declined progressively to 6,000–10,000 t. The decline was attributed to a decreasing broodstock leading to irregular spat settlement (Dao et al., 1992). For example, Bay of St. Brieuc production shrank from 12,000 t in 1973 to 5,000 t in 1980, and the Bay of Brest from 1,000 t before 1963 to <100 t during the 1980's.

[5] At 36.7 U.S. standard bushels in 1 metric ton

The semiclosed Bay of Brest was chosen to experiment with a large-scale restocking program based on hatchery spat production. In 1978, the first trials based on the spat repletion program yielded 40% adult scallops. They were followed by a large-scale program carried out between 1983 and 1988; the broodstock was estimated to be 300 t in 1990. Although efficient (i.e., 30% survival rate at 5 years old), concomitant research demonstrated that 80% of the larval settlement variability resulted from climatic conditions, therefore limiting the broodstock effect. Instead of producing broodstock, the management strategy for the Bay of Brest and Northern Brittany shifted to hatchery production of spat (2 mm length), a pregrowing phase in cages to a 30 mm length, bed seeding for growing, and fishing for the scallops when they were 3 years old (10.2–11 cm length).

Current Status

The main productive natural beds of scallops are located in the eastern part of the English Channel, namely Bay of Seine, offshore in the Mid-Channel, and in the Bay of St. Brieuc (150,000 ha) in northern Brittany (Fig. 17). Yearly landings reach 10,000 t, well below the total French consumption of about 50,000–60,000 t, divided equally among fresh, frozen, and processed products (Dao et al., 1992). Scallops with the roe attached, namely "coraillée," are considered a delicacy and reach F25–35 or $4.24–5.93/kg while nonmature scallops peak at F15–25 or $2.54–4.24/kg. Prices are highly variable and depend upon season, as well as supply and demand. Landed prices represent a total F250 million ($42.37 million).

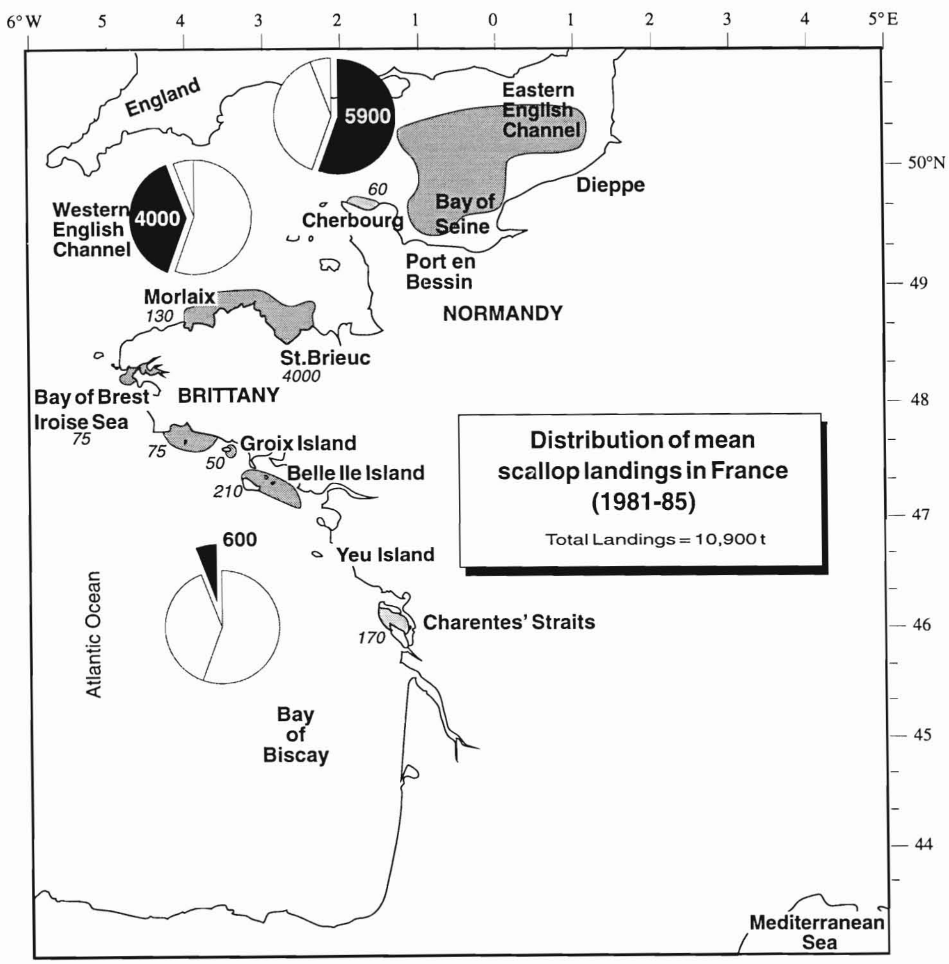


Figure 17
Distribution of mean landings (t) of the common scallop, *Pecten maximus*, between 1981 and 1985 in France.

The Scallop Fishery

The main feature of the 10 principal populations of *Pecten maximus* is highly variable recruitment, since this species is very sensitive to thermal fluctuations. A cohort abundance may vary from 1 to 10; it usually is harvested within 3 years (Dao et al., 1992). This high resource variability led to a complex management system based on administrative and professional regulations. The administrative management frame concerns legal marketable size, fishing gear, and season openings.

For the classified beds distributed within the 12-mile limit, additional regulations are proposed by professional organizations; they will then be ratified by decision makers. The regional fisheries committee, namely "Comité Régional des Pêches," and its scallop subcommittee, enacts regulations specific to each natural bed including licensee number; boat characteristics; fishing time and daily hours; dredge number and mesh size; annual, daily, and boat quotas; unloading harbors; and minimum legal size (e.g., from 10.2 to 11 cm). This committee also has the responsibility to specify the opening of the fishing season per area and eventually the closing of the fishery when the demand collapses. A minimum price limit is established by the producer organization, "Organisation de Producteurs," a special European status to optimize seafood markets.

During the 1980's, more than 3,500 fishermen and 1,000 boats were involved in the scallop fishery. In just the eastern part of the English Channel, 300 boats were harvesting scallops. Around 600–700 fishermen and 200 boats currently are involved in this fishery. Most scallop boats are 12–16 m long, and the crew size varies from 3 to 5. The current fishing season is between October and 15 May.

Although variable, the resource is predictable by stock assessments. The management system therefore aims to sustain the scallop population and secure the supply by limiting yearly landing variability instead of maximizing landings.

On the Mediterranean seaside, the scallop fishery has always been a bycatch for a fleet of bottom trawl and dredging boats. The minimum legal size for the great Mediterranean scallop is 7 cm. Landings peaked at around 100 t during the 1970's (Contat, 1983), but shrank to 33 t in 1982, to 15 t in 1988, and to a 5 t record low since 1990.

Scallop Culture

Based on the current fishery status, a cooperative program of scallop culture has been developed between scientists, professionals, and managers since 1988. Its originality is linked to the strong association of aquaculture and the fishery. The rearing cycle is characterized by:

1) Hatchery production of post-larvae (2 mm), using conditioned broodstock. Survival rate of larvae is around 40% in the hatchery and then 20% of settled spat survive in the nursery. At this stage, spat are set in flow-through systems at an initial density of 100,000 post larvae per unit;

2) A pre-growing phase is the second stage using rigid racks deployed on leased grounds in open sea. One container can be loaded with 250,000 spat in 27 racks and be easily moved from the surface. At 10–15 mm, scallops are sorted and density is halved; they reach 30 mm after 6 months. The survival rate reaches 35%.

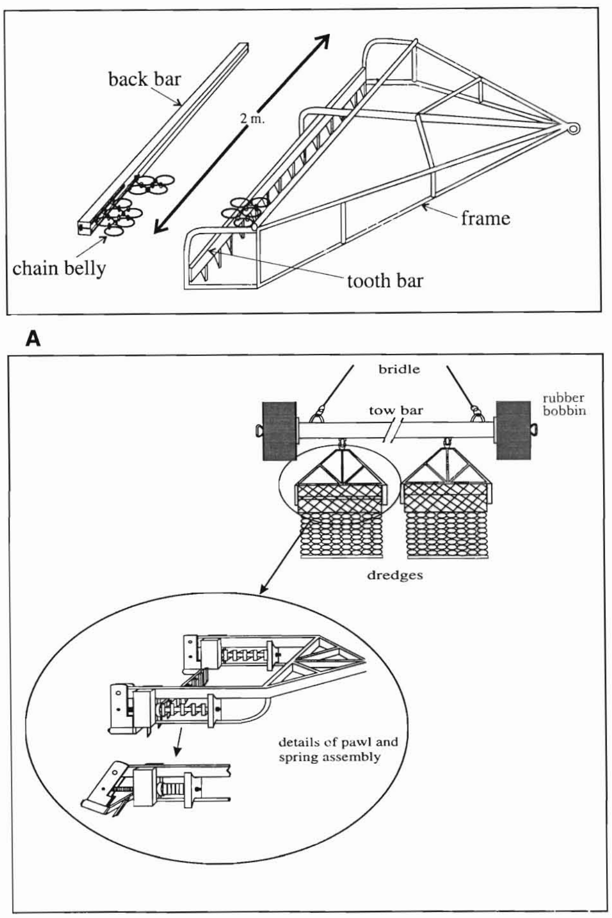
3) Scallops finally are deployed directly on the bottom, at a 5–20 m depth, and at an average density of 10 individuals/m^2. Scallops are dredged 2–3 years later when the marketable size of 10 cm is reached (125–150 g total weight). The capture rate varies between 20 and 50% in the most productive areas (Dao et al., 1992; Fleury and Dao, 1992). The overall survival rate from the larval to adult size is about 1%.

From a technical viewpoint, the rearing cycle is under control, but it requires further optimization since its cost-effectiveness depends primarily on the products' exchange value. For example, with a 30% yield and 150 g scallops, production costs reach around F15–25 or $2.54–4.24/kg above the 1994 fishery ex-vessel value.

Harvesting Methods

Dredges are the only gear used to harvest scallops. Several types currently are in use in France (Fig. 18a, b, 19) (Dupouy, 1978; Duval and Portier, In press). Their use depends primarily on regional peculiarities and regulations. For example, the dredge specifically used in the Bay of St. Brieuc is characterized by a diving board, a 200 kg maximum weight, a width of 2 m, with 7 cm tines spaced at 10 cm intervals, and an iron bag with 72 mm meshes. In northern Brittany as well as in the eastern part of the English Channel, the use of a spring-loaded dredge (80 cm wide) is increasing. On board, the crew usually operates two to four dredges (1.5 m wide). Scallopers can gear from 6 to 24 units when using spring-loaded dredges that are on bars, 6 units (dredges) to a bar. A boat towing 24 units would have 4 bars, 6 units on each.

Since scallops should be marketed alive, fishing activity lasts less than a day and the natural beds are near the main harbors (e.g., Port en Bessin, St. Brieuc, Dieppe). The largest boats in the eastern Channel, however, may spend 2–3 days offshore. The farthest natural beds are less than 80 miles from any harbor. The quota of 250 kg per fisherman is reached at the season opening; the daily catch ranges mostly between 0.7 and 1 t per boat.



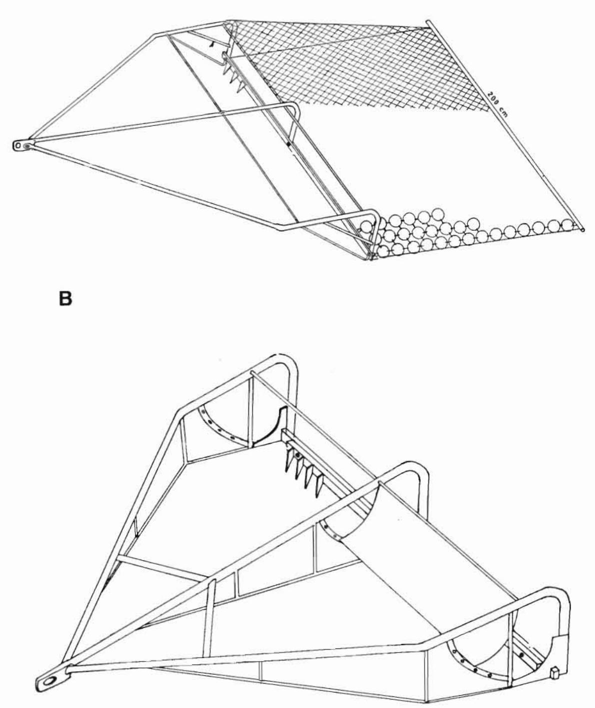


Figure 18 A, B
Various types of shellfish dredges (from Duval and Pourtier, In press, 18A; and Dupouy, 1978, 18B).

Processing and Marketing

Most scallops are marketed in the shell for the expensive fresh market. Landings of freshly shucked scallop meats, another part of the market, compete with imports from Scotland and England. French scallops are calibrated in the 10/30 and 10/20 meats per pound categories for the fishery and culture, respectively (Dao et al., 1992). The French market requires a high quality standard with less than 5% water loss during shucking. Most scallops for the frozen market as well as for processing plants are imported, except when the fishery supply is so high that a bottom price is reached. Frozen products usually are marketed by 2–5 kg packs or I.Q.F. (Individual Quick Frozen).

Other Mollusks

Among other important mollusks harvested in France, the squids, namely the common cuttlefish, *Sepia officinalis*; and the European squid, *Loligo vulgaris*, and veined squid, *Loligo forbesi*, combined; rank fifth and sixth in landings with 10,000 and 5,000 t, respectively (Chaussade and Corlay, 1988). They are caught using several types of fishing gear including squid jiggers, plastic pots, lures, seines, trammels, pelagic gillnets, bottom set gillnets, and bottom trawls (Boletzky, 1992).

The fisheries areas are located mainly in the English Channel and from southern Brittany to the Vendée region for the coastal fisheries, and the Bays of Biscay, Seine, and the Iroise Sea for the offshore fishery (Fig. 20). Squids are marketed as whole for the fresh market or frozen, as well as processed for the mantles, skinned fins, and skinned tubes. Ex-vessel values reach F10 or $1.69/kg for *Sepia* and F22 or $3.73/kg for *Loligo* sp.

Several other species are also the focus of important but local fisheries; statistical data regarding their landings are underestimated. The waved whelk, *B. undatum*, with 15,000 t (whole weight) landed (F45 million or $7.63 million landed value) is one. This species is mainly fished using plastic pots with cement bottoms weighing 12–15 kg and baited with fish and crab. In 1992, 60 boats were potting them in the Gulf of St. Malo where 90% of the catch was landed. Each boat is <10 m long and has a crew of 2–3. Since the development of the

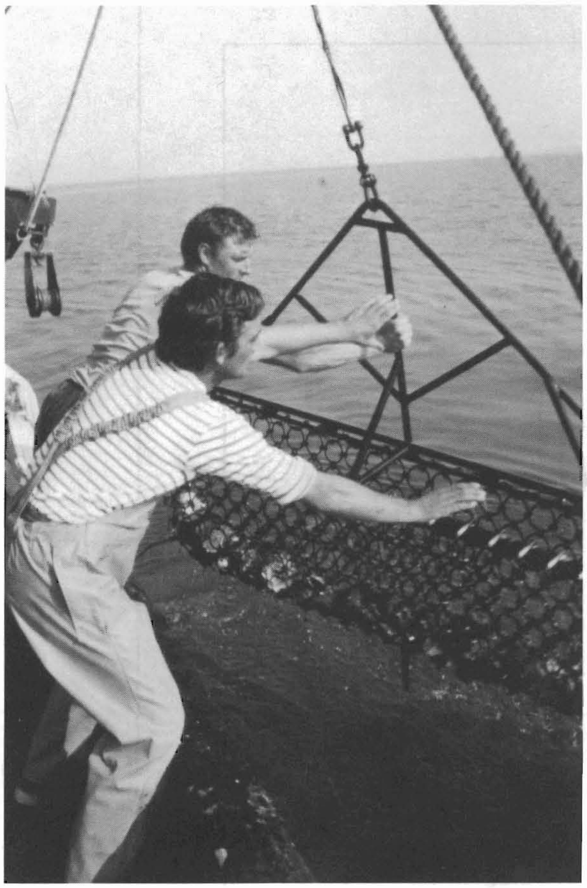


Figure 19
Crew taking in a scallop, *Pecten maximus*, dredge.

hydraulic pot hauler during the 1980's, the fishing effort has increased substantially and a boat can lift 500 pots a day (Véron, 1992). Pots are distributed every 5–10 m along trot (boltch) lines (50–60 m long). Most of the catch is sold to the French fresh market, but some is exported to Belgium.

On the Mediterranean seaside, the purple dye murex, *Murex brandaris*, is a bycatch of the bottom trawler fleet in the Gulf of Lion. The trawlers use a special fishing gear, named "radasse," which is built like a beam trawl, using pieces of fishing net 8 m long. The murex have spines that become caught in the net. The "radasse" is trawled at 1–2 knots for 2.5 hours/tow on the fishing grounds. The murex are removed from it when the vessel returns to its harbor (Véron and Raimbault, 1992). This fishery lands around 100 t (whole weight)/year for an ex-vessel value of F3 million ($ 0.5 million).

Abalones, *Haliotis tuberculata* var. *tuberculata* on the Atlantic coast and *Haliotis tuberculata* var. *lamellosa* on Mediterranean coast, usually are harvested by local fishermen at low tide or by divers. On the Atlantic coast, where abalones have been overfished, regulations restrict the harvesting to intertidal areas. In contrast, large subtidal populations recently were reported mainly in the Gulf of St. Malo, and a limited fishery based on a license and quota system was initiated during the 1990's.

Abalones (8 cm minimum legal size) are harvested year-round, except during their July and August reproductive period. The fishery is carried out by scuba divers who use knives to remove the abalones from rocks. Landings are about 20 t (whole weight) a year. All landings must be reported to the Administration. Illegal fishing is often reported despite the regulations and enforcement and is thought to run at least 100 t a year. Abalone is the most expensive mollusk on the French market and costs around F100 or $17/kg. Most of the catch (90%), however, is processed for export to Japan.

During the 1970's, culture experiments were carried out to control the rearing cycle. Although hatchery rearing was under control, the growout stages were too long (i.e. 3–4 years) and not cost-effective. In 1994, new techniques using underground seawater were being tested to improve the efficacy of the rearing cycle.

Two additional pectinids, the queen scallop, *Aequipecten opercularis*, and the variegated scallop, *Chlamys varia*, are the targets of dredgers and trawlers in the English Channel and the Bay of Brest (Fig. 17). The queen scallop is the only authorized bivalve caught by bottom trawlers (Dao and Decamps, 1992). This species is fragile, which limits its commercial interest, and is marketed only fresh. Around 2,000–3,000 t are harvested each year mainly in the western English Channel (>1,000 t by 15 trawlers) and the eastern English Channel (>1,000 t by 30–40 dredgers and trawlers).

Instability of the natural scallop beds results largely from irregular recruitment and patchy distribution. The variegated scallop used to be harvested in the Charentes' straits, i.e., "Pertuis charentais," yielding a record high of 2,000 t during the 1960's. Harvesting ended in the 1970's when heavy fishing decimated the populations.

The remaining dredging activity now is located in the Bay of Brest where yearly landings are between 200 and 400 t. This species reaches the minimum legal size of 40 mm at 2 years old. Strict regulations limit harvesting to licensees from November to the following February (Dao and Decamps, 1992). Culture experiments were done using natural and hatchery spat from 1989 to 1991, particularly by reseeding spat in oyster ponds. Although growth rates were faster than in natural populations and market size was reached in less than a year, survival rates were still too low to expect a full implementation of this rearing cycle.

The cockle, *Cerastoderma edule*, fishery yields around 10,000 t (F33 million or $5.59 million landed value) a year (the landed quantity is underestimated). Cockles (minimum legal size 30 mm) usually are harvested at

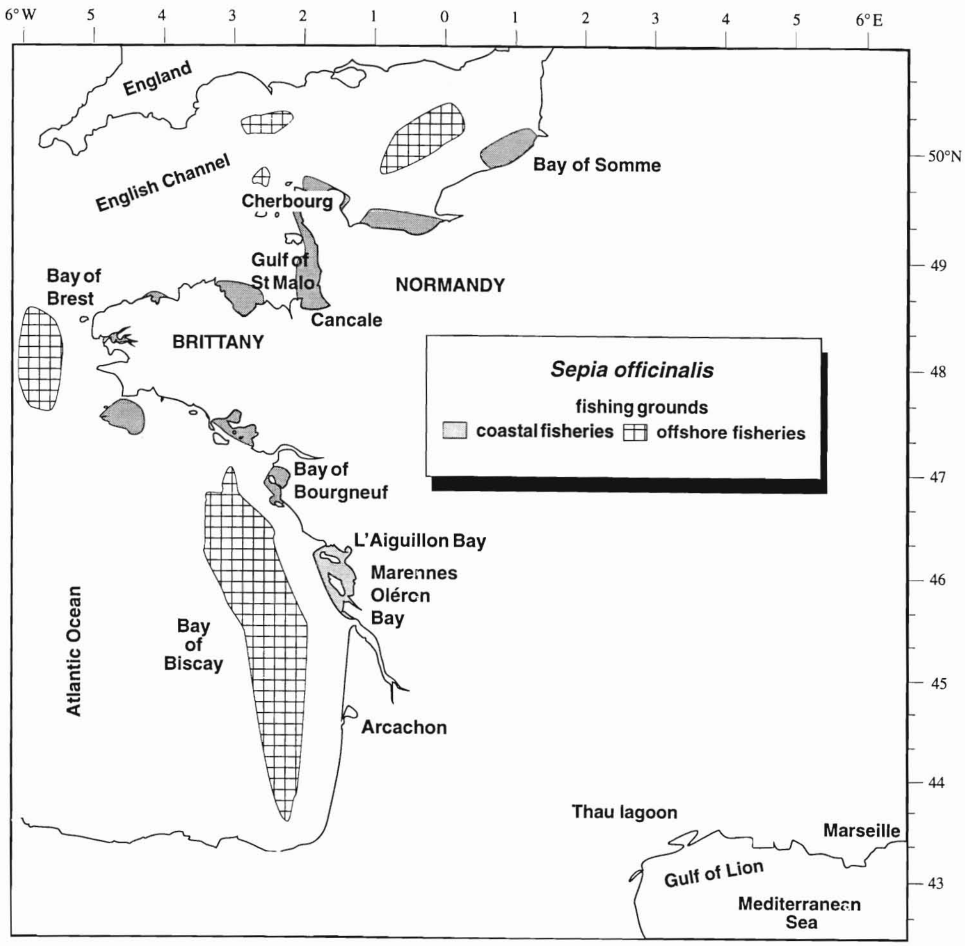


Figure 20

The offshore and coastal fishing grounds for squid, *Sepia officinalis*, along the French coast.

low tide by hand picking or using hand rakes along the Atlantic and English Channel coasts. A commercial reseeding activity is also carried out in southern Brittany (Le Croisic) where spat are deployed in culture plots at a density of 1,000 individuals/m^2; landings are 2,000–3,000 t a year.

Several venerid clam species are also the focus of extensive fisheries. In 1861 and 1863, Coste introduced the northern quahog, *Mercenaria mercenaria*, to France in Arcachon Bay (Ruckebusch, 1949; Lambert, 1949). The first clam batch reached 2 cm 2 years later, but the quahogs failed to reproduce. Later on, from 1936 to 1939, other trials were carried out in southern Brittany (Belon River), but the quahogs again failed to reproduce. Meanwhile, at the turn of the century (1910), an oyster farmer named Prunier introduced several quahogs to the upper Seudre estuary (Marennes-Oléron Bay) where they successfully reproduced. Since then, natural, but sparse, quahog beds have been reported in several places including southern Brittany; their presence demonstrates successful reproduction (Lambert, 1949).

During the 1940's, the northern quahog was the focus of culture in the Seudre estuary. Small quahogs were reseeded in oyster ponds as a byproduct of the oyster industry. Since then, quahogs have been harvested by hand raking and hand picking in this estuary. Dredges currently are used for harvesting quahogs in sandy-muddy bottoms in southern Brittany (Morbihan). Additional trials using hatchery spat were made during the 1970's, but a slow growth rate and the quahog distribution deep in mud bottoms limited the cost-effectiveness of the culture, particularly when compared with the Manila clam. The current activity centers on a small fishery limited to the Seudre estuary and southern Brittany, and a bycatch elsewhere.

The warty venus, *Venus verrucosa*, is dredged for the fresh market from September to April mostly in the

Gulf of St. Malo (95%); the remaining landings are in northern and southern Brittany (Berthou, 1992). The fishery, initiated during the 1950's, yielded a record high of 5,000 t in 1962 and 1975, declined afterward to 4,400 t in the early 1980's, and to 1,400 t in 1988. In 1986, 183 dredging boats were operating in this fishery, with 75 working more than 6 months a year. Despite the decline in landings, the fishery has remained attractive since the ex-vessel value, although variable, has increased to F20–50 or $3.40–8.50/kg. The dredge in use is specific for bivalves, rigid, with a 60 cm opening and an 8–25 cm flat board. The metallic frame has 21–25 mm grid spacing to retain only legal size clams (40 mm).

The banded carpet shell, *Venerupis rhomboides*, is also harvested exclusively by dredging in the Gulf of St. Malo and southern Brittany (Berthou, 1992). The minimum legal size is 38 mm. In 1988, 800 t were dredged for the fresh, processed, and frozen markets as well as for export.

The dredging fishery of the common European bittersweet, *Glycymeris glycymeris*, yields 2,000–2,500 t a year in the Gulf of St. Malo, southern Brittany, and Iroise Sea for the fresh market. This underexploited population would present a large potential for processing if meat tenderizing techniques were developed (Berthou, 1992).

In the same areas, dredging boats harvest around 5,000 t/year of thick trough shells, *Spisula ovalis*, and *S. solida*. The clams average about 35 mm long (range, 28–45 mm); the minimum legal size is 28 mm. Most are sold for the fresh market, and the remainder are processed and frozen for southern European countries. Only one year class usually is found in the natural beds, leading to nearly complete harvesting of local subpopulations. The populations are characterized by good sets every year and rapid growth of the clams. When fishermen shift their activity to other species or other natural beds, the *Spisula* populations recover quickly (Berthou, 1992).

Bycatches of the previously cited fisheries include the golden carpet shell, *Venerupis aurea*; chamber venus, *Circumphalus casina* and *C. rosalina*; smooth callista, *Callista chione*; sand gaper, *Mya* sp.; mature dosinia, *Dosinia* sp.; tellins, *Tellina* spp.; and otter shells, *Lutraria* sp.

In addition, there are small fisheries that involve digging by hand and with rakes. The mollusks harvested include the peppery furrow, *Scorbicularia plana*; several donaxes, *Donax* spp.; razor shells, *Solen* sp.; rayed trough shell, *Mactra corallina*; and grey trough shell, *M. glauca*.

Shellfish Preparation for Consumption

Most of the French molluscan production is marketed fresh in the shell. The mollusks are washed and graded by size. Some species (e.g., clams and scallops) can be marketed frozen. Freshness is the main criterion for French consumers, and, when required, preparation and cooking are carried out on their own. Therefore, any breading operation before marketing is rare and concerns only clams. Battered processing for shellfish does not exist in France. Canning is developed to a very limited extent and concerns only the species of low exchange values such as mussels, clams, and bycatch species from the dredging fisheries on natural beds. A small market has been initiated for smoked mussels, but the demand is low since they do not yet fit French consumption habits.

Mollusks are eaten several ways in France, including raw, cooked using various recipes, boiled, and steamed. Oysters and most of the clam species are eaten raw, and, to a limited extent, the new French cuisine has developed consumption of raw scallop, *P. maximus*, adductor muscles. Recipes are available for all shellfish species previously cited, including oysters. However, with oysters, this represents a very limited consumption and is mostly proposed by restaurants. When cooked, clams are often prepared using butter and culinary herb stuffings. Since abalone muscle is very tough, it must be tenderized with a mallet. The waved whelk, *B. undatum*, and the periwinkle, *Littorina littorea*, are the only species usually boiled in salty water and culinary herbs. Species that are steamed include mussels, cockles, clams, and sometimes scallops. The steaming process requires added ingredients such as white wine and culinary herbs.

Aquaculture and Fishery Management

Since the coastal area is the focus of multipurpose use, state regulations are required to facilitate various and simultaneous activities. For example, the 1986 state law, "Loi du Littoral," specifies the legal framework regarding coastal management. Two types of spatial management, namely "Schéma d'Aménagement et de Mise en Valeur de la Mer (SAUM)" and "Schéma de Mise en Valeur de la Mer (SMVM)" usually are proposed to organize the coastal area by specifying priority uses. The management plans are proposed by the state managers in agreement with local representatives, scientists, and administrators. A public survey meanwhile is carried out to debate the proposals.

Regarding the marine-related activities, fishermen benefit from a professional organization developed at local, regional, and national levels, and funded by taxes on business dealings. At each level, representatives of each profession are elected on an equal basis of employers and employees. Forty-eight local fishery committees, namely "Comité Local des Pêches," are distributed along the French coast. At the second level, four regional committees (i.e., Normandy, Brittany, Southwest, and Mediterranean Regions) represent the fishermen's interests in relation to the regional administration. Moreover, 18 interprofessional national committees are specialized in problems dealing with one species or a species group, i.e., "Tuna committee," "Scallop committee," to organize the fisheries.

Besides the fishery, shellfish culture has a national and nine regional committees to organize the industry. Like the fishery organization, funds are provided from taxes on commercial activities. The regional committee involves state managers, scientists, and professional organizations, and it enacts the global rules and authorizations for use of the leasing grounds that remain inalienable and under state management. For example, in the Marennes-Oléron Bay, the surface area of tables used in oyster culture should not total more than one-third of the leased acreage, and no more than 6,000–7,000 oyster bags should be placed in a hectare. In Normandy, the upper threshold is 5,000 and 6,000 oyster bags/ha on the eastern and western coasts of Cotentin, respectively. The committee debate to allot each leasing ground to applicants is based on a regional management plan, i.e., "Schéma des structures," which lists priority rules. A public survey meanwhile allows a debate over the use of each leasing ground, and recommendations are considered by the committee.

The national council of fisheries and mariculture, "Comité Central des Pêches et Cultures Marines" overviews all committees, the entire organization, and aims to provide information and improve relationships between sea-related activities and the Administration.

Public Health

Since the French shellfish market is based mainly on raw and fresh products, it is particularly important to protect the public from eating polluted or unhealthy products. Several regulations are enforced to avoid public health problems. The main framework relies on several national monitoring networks managed by IFREMER, the French Research Institute for Sea Exploitation. They include 1) the monitoring network of the coastal environment or "RNO," 2) the Phytoplanktonic monitoring network or "REPHY," and 3) the Microbiological monitoring network or "REMI" (for reviews, see Belin et al. (1993) and Berthomé (1992)). However, public health is only one of several objectives of the networks; others are marine life and environmental protection, trends, and risk assessments of environmental variables and contaminants. The networks are funded by the Ministry of Environment, Ministry of Research and Technology, and by shellfish farmers through professional taxes.

Coastal Environment Monitoring Network, "RNO"

The Coastal Environment Monitoring Network, "RNO," was started in 1974 for the water quality survey and marine life and sediment surveys that began in 1978. It resulted from the international treaty enforcements of London and Oslo (1972), Paris (1974), and Barcelona (1976). The main objectives are the monitoring of yearly trends and thresholds of seawater variables (e.g., temperature, salinity, oxygen, nutrients). Contaminant concentrations are determined four times a year in fish, oysters, and mussels at 43 sites along the French coast representing more than 100 experimental stations. Heavy metals (i.e., mercury, cadmium, lead, zinc, and copper), PCB, PAH, and organochlorines (i.e., DDT, DDD, DDE, HCH, and Lindane) are systematically analyzed.

Phytoplanktonic Monitoring Network, "REPHY"

The toxic (DSP) phytoplanktonic blooms of *Dinophysis* sp. that occurred in 1983 and resulted in hundreds of gastroenteritis cases prompted managers to establish a monitoring network to 1) protect public health, 2) protect shellfish beds, and 3) develop a long-term data base. This survey, called the Phytoplanktonic Monitoring Network, "REPHY," and initiated in 1984, has facilitated the systematic sampling of phytoplanktonic population trends and associated phenomena, as well as early detection of abnormal phenomena along the French coast. As soon as the latter is detected, an intensive survey assesses spatiotemporal fluctuations to provide insights for decision makers. Thirty-seven sectors currently are systematically surveyed monthly from September to April and weekly from May to August. When an abnormal event (e.g., gastroenteritis) or a toxic algal bloom is detected at an early stage, 73 additional sites are added to the regular monitoring. When DSP or PSP toxins are detected by scientific tests, the area is closed by state officials to impede any shellfish sales until two negative tests (i.e., two consecutive weeks) are reported.

Microbiological Monitoring Network, "REMI"

Early in the century, bacteriological control of oysters was established by private funds to guarantee shellfish quality. The state agency, Office Scientifique et Techniques des Pêches Maritimes, OSTPM, took over this bacteriological control in 1919 and organized a national network, now called the Microbiological Monitoring Network, "REMI." In 1989, the monitoring network was reorganized to include environmental quality concerns. The global approach focusing on trends and thresholds is based on fecal coliform concentration (i.e., number per 100 ml of meat) and, to a lesser extent, on *Salmonella* occurrence as contamination indicators. In 1992, 345 stations were monitored monthly along the entire French coast (5,500 km). More specifically in the mollusk farming areas and for the public health concern, the monitoring effort is increased to a weekly survey as soon as abnormal environmental conditions occur (e.g., heavy rains, agricultural practices in the watershed, tourism activity). In addition to the increased frequency, the sampling incorporates additional stations that total 278 nationally. Fecal coliforms and *Salmonella* are systematically surveyed. The fecal contamination concentration is particularly important with regards to the French and European regulations that allow only direct commercialization without further treatment below a 300 coli./100 ml meat threshold. No *Salmonella* is tolerated before marketing.

The Future

In the past, the molluscan fisheries sector has shown irregular landings due to abnormal recruitment and excessive fishing effort. Improved stock assessments and specific knowledge of factors affecting recruitment therefore are likely to improve the fishing industry economy. Although successful in several areas (e.g., scallop fishery in the Bay of St. Brieuc), comprehensive management plans, including regulation enforcement based on statistical stocks assessments, appear necessary for the natural shellfish beds showing high potential production (e.g., abalone). Fishing effort on current bycatch species (e.g., dredged clams) is particularly likely to increase and provide landings for the processors and markets. In contrast, it seems difficult to implement management plans for species showing a short life cycle and fast population recovery (e.g., mussel, cockle, and *Spisula* sp.). In other respects, it is unknown to what extent the current crisis affecting European finfisheries will affect molluscan landings.

The culture of mollusks has been a large success in France for several reasons including the extent of the natural spatfall, high ecosystem carrying capacity, good management, and good adaptation of the mollusks to cultural practices. Past events have shown that the industry can be harmed, however, by epizootic diseases or abnormal events such as dinoflagellate blooms. Markets and production can be affected. Scientific research is critical to protect public health and optimize current production.

One key element is to improve the balance between the ecosystem carrying capacity and the mollusk stocking density. For example, Héral et al. (1986) have demonstrated that oyster production in the Bay of Marennes-Oléron cannot be higher than 40,000 t for a stocking density between 90,000 and 200,000 t. Increased stocking density resulted in increased mortality rates and growth rate decline. This is a critical issue, since optimum stocking densities should be defined specifically for each rearing area, to maintain quality products as well as healthy shellfish populations, therefore limiting a risk of disease occurrence. The second key element for a sustainable industry is to prevent water quality degradation, as a guarantee for quality products (e.g., bacteriological quality). The intensive monitoring networks already developed will facilitate early reports to address the issues of abnormal events. For example, the networks will likely lead to additional improved watershed management as well as plant equipment with regard to recent EU sanitary regulations that rate the rearing areas according to water quality criteria.

Further industry advancements will be achieved by developing automatic equipment and longline techniques, which should result in improved labor conditions, reduced labor costs, and development of offshore culture in unexploited areas. Other ways to improve the shellfish industry are anticipated in the near future by implementing current research programs. For example, disease resistant strains (e.g., *O. edulis* against *Bonamia* sp.) and genetically manipulated animals currently are under review. Hatchery-produced spat from such strains would be a way to improve shellfish production.

From a marketing viewpoint, the EU development will obviously expand shellfish market possibilities within European countries and could result in increased production. Official recognition of local labels, appellations, and brand names is likely to occur in the next few years, facilitating product sales. However, new development should be considered concomitant with bioeconomic analysis of the shellfish industry. Coupling models of production dynamics with marketing systems will improve overall cost-effectiveness. It seems important also to take into account social and political approaches to facilitate sustainable development, since they are key elements in industry dynamics. New conflicts in watershed, freshwater, and coastal space uses are already anticipated, requiring insights and specific knowledge for the decision making process.

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The Mussel, Oyster, Clam, and Pectinid Fisheries of Spain

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ABSTRACT

Spain produces several molluscan species, including mussels, oysters, cockles, clams, and scallops. Nearly all grow in the Galician region in the northwest. Spain's production of 200,000 t of blue mussels, *Mytilus galloprovincialis*, per year, makes it the second largest producer of cultured mussels in the world. Historically, mussels were consumed in Roman villages and later by coastal peoples. They became important when farmers began culturing them in the early 1900's. In 1946, raft culture was introduced and production increased sharply. A sheltered environment is provided by flooded river valleys ("rias") for culturing the mussels on ropes suspended from floating rafts. Farmers collect mussel seed from local shores, attach the seed to the ropes, and grow them to market size in 13 to 16 months. In 1984, there were 3,347 mussel rafts. Each produces an average of 47 t/year. About 7,000 people farm mussels and 3,000 more are engaged in related industries. Production of the flat oyster, *Ostrea edulis*, is limited with about 500 t/year. The cockle, *Cerastoderma edule*, is harvested mainly from natural beds and also is cultured in protected parks; production is about 1,300 t/year. The clam fishery targets *Tapes decussata*, *Venerupis pullastra*, and *V. rhomboideus*. Total production of clams is about 2,000 t, all from natural areas. Three scallop species have commercial importance: *Pecten maximus*, *Chlamys varia*, and *C. opercularis*. *P. maximus* is cultured on a small scale by attaching to ropes 10-cm seed collected from natural beds and suspending them from rafts for growth. All bivalves from natural beds and rafts must be treated in one of 54 depuration stations.

Introduction

The waters of Spain have several species of mollusks which have been gathered and farmed commercially for many years. They include mussels, oysters, cockles, clams, and scallops. Nearly all grow in the Galician region of northwestern Spain.

Mussel Fishery

Spain, producing about 200,000 metric tons (t) of blue mussels, *Mytilus galloprovinciallis*, per year, is the second largest producer of cultured mussels in the world. Mussels also comprise more than 95% of Spain's total mollusk production; they are mainly cultured in the Galician Region in northwestern Spain (Figueras, 1989).

Habitat Description

The Galician coast (Fig. 1), about 1,309 km long, is characterized by flooded river valleys called "rias," where farmers culture the mussels. Rias are up to 25 km long, between 2 and 25 km wide, and from 40 to 60 m deep; their bottoms are muddy, and they are bordered by hills (Andreu, 1958). Annual productivity in the rias averages 10.5 mg carbon/liter/hour. The temperature ranges from 10° to 20°C, the salinity is around 34 ‰, and the tidal range averages 4 m. Tidal currents are strong. There is a continuous upwelling of cold water rich in nutrients, and these along with nutrients which wash in from the hills during heavy rains (mean annual precipitation is 1,250 mm) probably stimulate an abundance of phytoplankton. This, in turn, favors the growth of mussels (Andreu, 1976; Iglesias et al., 1984; Figueras, 1989). The sheltered rias provide an ideal environment for culturing mussels on ropes suspended from floating rafts (Lutz et al., 1991). The most important culture area is the ria de Arosa which is responsible for 60% of Spain's mussels; it is followed by ria de Vigo and ria de Pontevedra (Fig. 1).

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Natural populations of mussels are present in large areas in mouths of the rias and islands on intertidal rocky shores, where the mean density in the most crowded beds is around 24,000 mussels/m^2. They also grow along the rias mainly on rocky areas, cliffs, and boulders. Farmers collect mussel seed from these areas to suspend from their rafts. Recruitment of seed mussels occurs throughout the year with the major settlement season from May to September.

Associated Species and Predators

The associated species that occur in the natural mussel beds are those found on rocky intertidal shores, such as barnacles, *Balanus* sp., and algae, *Enteromorpha* sp. Mussel predators include crabs, *Carcinus maenas*; starfish, *Asterias rubens*; and sea birds. The associated species that colonize the mussels on ropes suspended from rafts, by means of planktonic larvae or crawling, are

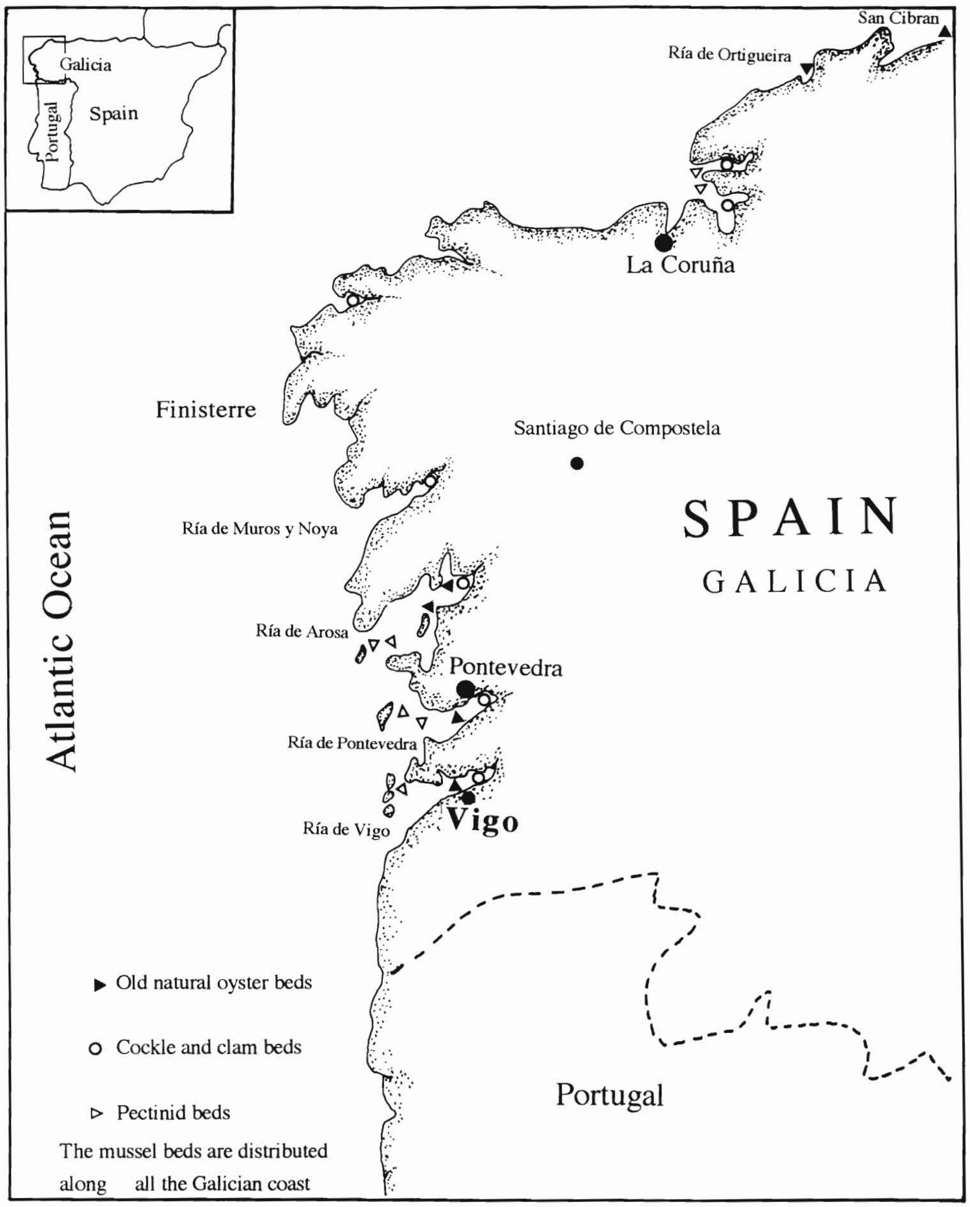


Figure 1
The Galician region of Spain, showing the rias, old natural oyster beds, and the actual mussel, cockle, clam and pectinid beds.

crustaceans such as the decapod *Pisidia longicornis*; amphipods, *Phtisica marina* and *Eurystheus maculatus*; ascidians, *Ascidiella aspersa* and *Ciona intestinalis*; and encrusting species such as balanids and polychaete worms, *Pomatoceros* sp. and *Elminius modestus*. They compete with each other for space and food and some can invade the mussel shells. Damage from crabs and starfish is slight, but occasionally *A. rubens* and *Nucella lapillus*, a gastropod, occur on the ropes. In addition, some fishes, such as the sparid, *Diplodus sargus*, and golden mackerel, *Sparus aurata*, occasionally damage adult mussels by crushing their shells; they also eat seed mussels. The parasitic copepod, *Mytilicola intestinalis*, which has been associated with damage to cultured mussels in other countries, does not cause serious harm. Recently, the parasite *Marteilia* sp. was found in mussels, but it did not cause any serious harm. Farmers eliminate the associates and predators on the ropes by hand when they thin the mussels (Andreu, 1976; Perez and Roman, 1979; Gonzalez, 1982; Figueras, 1982; and Figueras et al., 1991).

History of the Fishery

The earliest evidences of mussel consumption in the Galician Region has been dated in the fourth century B.C., when the natives left large deposits of bivalve mollusks shells including mussels. These deposits, denominated "Concheiros," have also been found near the Romanic villages of the first century A.D. (DEMARSA, 1965; De La Pena[1]). In the 16th century, people from Portugal came to the ria of Arosa, in Cambados, to gather mussels, clams, and cockles (Ferreira, 1988). Mussels became important in Spain when farmers began culturing them at the beginning of the 20th century. The first mussel culture was practiced in Tarragona and Barcelona (northeast of the Iberian peninsula) in 1901 and 1909, respectively, using poles similar to those used in France. After the first trials, this system was abandoned and use of floating structures began. At this time, the natural populations of mussels in the Galician rias were used mainly as manure on farms and, on a limited scale, as a source of mussel seed to be cultured. There were a few parks where farmers practiced bottom culture of mussels; the mussels were sold along the Mediterranean coast. In 1946 raft culture of mussels was introduced in the Galician region and in a few years production increased sharply (Andreu, 1958, 1962, 1963, 1968; Bardach et al., 1972).

The early rafts consisted of square wooden frameworks suported by a central float and restored old ships that supported wooden frameworks, from which farmers hung ropes of spart grass (*Spartium junceum*) (Fig. 2). Farmers attached mussel seed to the ropes, and when the seed reached commercial size, they collected them by hand or with a special pin wheel (Andreu, 1958; Canel, 1968; Nunez and Castro, 1990). Subsequently, the old ships were replaced by square or rectangular wooden frameworks supporting small houses. Flotation consisted of wooden floats wrapped in wire mesh and coated with concrete.

Today, a few old rafts remain, but most of the new ones are constructed of a framework of eucalyptus wood. Their size varies considerably from less than 100 m^2 to more than 500 m^2 (Perez Camacho et al., 1991). These structures are supported by from one to six floats constructed of wood or steel, covered with fiberglass or

[1] De La Pena, A. Archaeologist, Museo de Pontevedra, Pasanteria #10, Pontevedra, Espana. Personal commun., Aug. 1992.

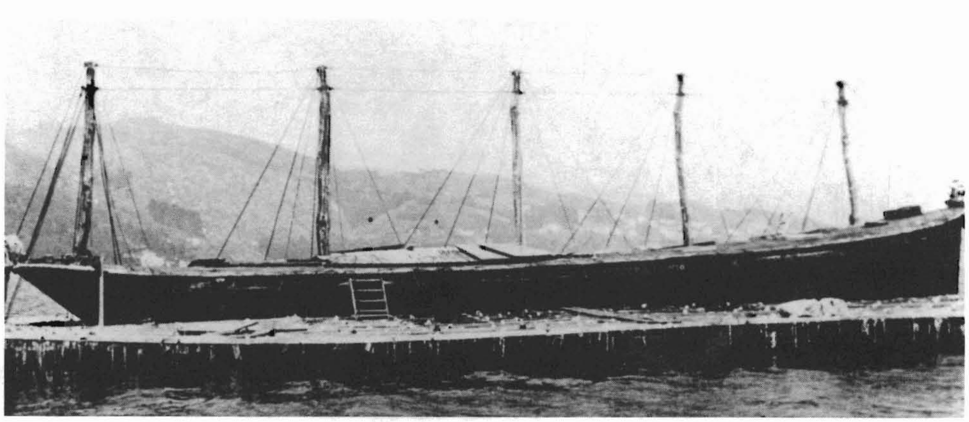


Figure 2
An old mussel culture raft in the ria de Vigo.

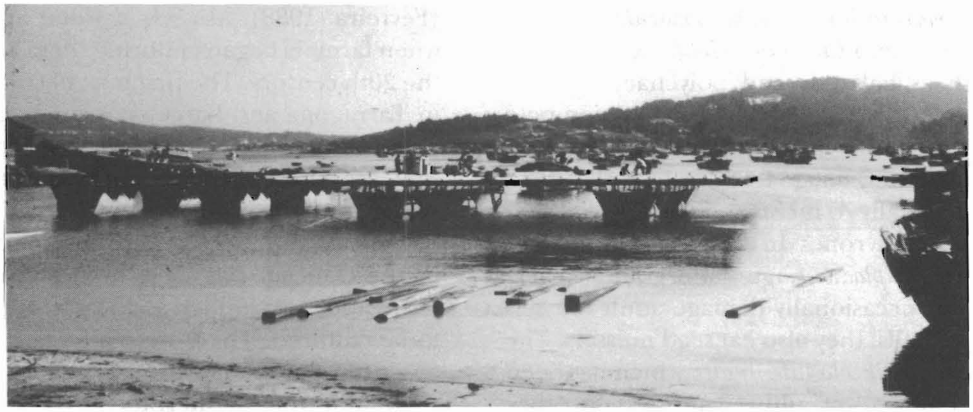


Figure 3
A current mussel-culture raft in a shipyard of the ria de Vigo.

polyester, or filled with expanded polyester (Fig. 3). Depending on the number of floats, the usable culture area can be from 80%, when a central float is used, to 90%, when from four to six floats are used (Perez Camacho et al., 1991). Farmers secure the rafts with one or two iron chains and a 20 t concrete anchor. In protected areas with little boat traffic, they use only one mooring chain. Two chains are better in exposed areas or when the rafts are near the shore or heavy boat traffic (Bardach et al., 1972). The rafts are located together, separated about 80–100 m from each other, in groups called parks (Fig. 4). These vary in number of rafts, and their locations are regulated by marine authorities. From the beginning of mussel culture in 1946, the number of rafts increased moderately to 400 in 1956, but after that, it increased rapidly (Table 1). The average size of the rafts increased from 297 m^2 in 1977 to 369 m^2 in 1984 (Perez Camacho et al., 1991). The actual standard size of the rafts is 500 m^2. Currently, farmers work from shallow-draft, wide-beam boats (9 t in weight), powered by diesel engines of about 24 hp. Each has a basket and crane to raise the ropes and machines to separate and thin the mussels (Nunez and Castro, 1990).

Culture Methods

Mussel culture is divided into five stages: 1) seeding or procuring the seed, 2) attaching seed to the ropes, 3) thinning, 4) growing, and 5) harvesting.

Figure 4
Aerial view of the mussel culture rafts in the ria de Arosa.

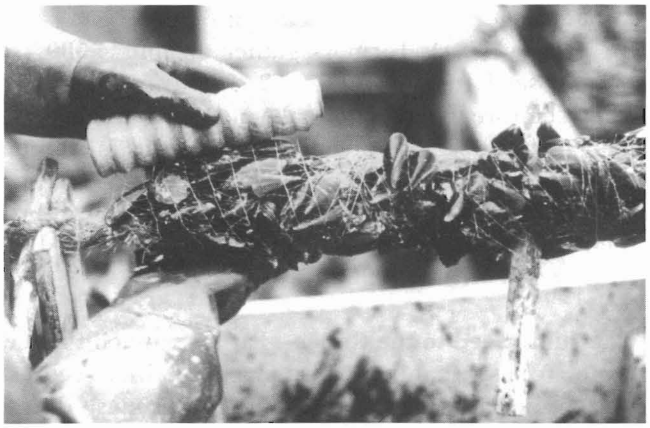
Table 1
Number of rafts and production of mussels from 1956 to 1995, modified from IUEDG (1989) and MAR (1991).

Year	Rafts	Production (t)
1946	10	
1956	410	22,460
1958	707	39,700
1959	909	50,900
1960	1,099	61,550
1962	1,327	74,300
1963	1,424	79,750
1965	1,684	94,300
1966	2,050	114,800
1967	2,615	146,450
1968	2,786	156,000
1972	2,996	167,800
1975	3,134	175,500
1976	3,095	
1987	3,242	200,000
1989	3,347	
1995	3,386	230,000

Seeding or Procuring Seed—Culture begins when farmers collect mussel seed mainly from the natural beds (60–70%) and the remainder from the collector ropes hung from their rafts. Farmers can collect up to 1,500 kg of seed per low tide in about 4 hours from the exposed rocky shores on the ocean side of the rias and islands (Fig. 5) (Figueras, 1989). They use a special steel shovel, called a "rasqueta," which has a blade about 10 cm^2 attached to a wooden handle. Farmers suspend the mussels from their own rafts or sell them to other farmers. The price is about 60 pesetas/kg (125 pesetas = US$1). Farmers gather around 4,500 t of mussel seed (mean length = 2 cm) from these areas every culture cycle. They take the seed to the rafts, keeping it moist, and attach it to ropes within 24 hours after collection. To collect seed from the rafts, farmers use special collectors made from old fish nets and suspend them during March and April (Andreu, 1958; Nunez and Castro, 1990).

Attaching Seed to the Ropes—Farmers attach the seed to the ropes by hand or with a machine which secures it with a special cotton or rayon mesh; this mesh disintegrates within a few days (Fig. 6). By then, the mussels have secreted new byssuses and have attached themselves to the ropes. Farmers attach from 1.5 to 1.75 kg of seed per meter of rope, and the average weight of seed for a rope is 14 kg (Figueras, 1989). The ropes, usually 3 cm thick and made of nylon, polyethylene, and sometimes spart grass, vary in length from 6 to 10 m. Their rough surfaces facilitate the attachment of the mussels. Each rope with attached mussels has a loop at one end, which is fastened to a thinner polyester rope called a "rabiza" (12–14 mm thick), which in turn is lashed to the girders of the rafts. The rabiza usually lasts only 3–4 years because it is exposed to air and sunlight (Figueras, 1989), while the major rope lasts an average of 6 years (Perez Camacho et al., 1991). Each raft has from 200 to 700 ropes. Every 30–40 cm, wooden or plastic pegs 20–30 cm long are inserted between strands

Figure 5
A mussel bed on the oceanic side of the ria de Vigo.



a

Figure 6

a. Wrapping the mussels with a rayon net. b. Filling sacks with mussels.

b

of the ropes to prevent the clumps of mussels from sliding down (Fig. 7) (Figueras, 1989; Nunez and Castro, 1990; Perez Camacho et al., 1991). Farmers attach from 1 to 3 ropes/m^2 of raft. This distribution allows an adequate flow of water rich in food for the mussels and prevents the mussel ropes from touching each other (Figueras, 1989). Farmers install the ropes mainly from November to March (Perez Camacho et al., 1991).

Thinning—The third step is thinning, which has to be done to prevent the mussels from falling off in rough weather; thinning also favors their fast and uniform growth (Figueras, 1989; Nunez and Castro, 1990). Farmers do this when the mussels are half grown (shell length 4–5 cm) after 5–6 months of growth, usually from June to October (Figueras, 1989; Nunez and Castro, 1990). They bring the ropes into their boats using a crane and rub off the clusters of mussels by hand into a steel screen which separates them into different sizes. A mechanic cylindrical screen can also be used (Fig. 8). The mussels from each original rope are attached to two to four new ropes (SOMEGA, 1975; Figueras, 1989) with cotton or rayon netting. The average weight of the ropes is 46 kg (Perez Camacho et al., 1991). Those farmers who automate this operation spend 5–15 seconds per m of rope, or less than 14 hours for 500 ropes of 10 m length (Figueras, 1989). This work is repeated once again before harvesting, if the mussels grow rapidly and their weight and density increases the risk that the mussel clusters will fall off. It is also necessary when farmers have to ensure that all mussels reach similar size at harvest time (Bardach et al., 1972; Figueras, 1989).

Growing—The growth of mussels constitutes the fourth culture step. In the Galician region, where this growth is fast, mussels can attain market size (8–10 cm) in 13–16 months, especially in the areas closest to the ocean side of the rias. The usual time required in some bays is around 14 months. However, a high density of rafts in the bays can slow the mussel growth (Figueras, 1989). Growth of mussels is minimal in summer and highest in winter. Slow summer growth is related to the relative paucity of plankton in the stratified water then, and it is

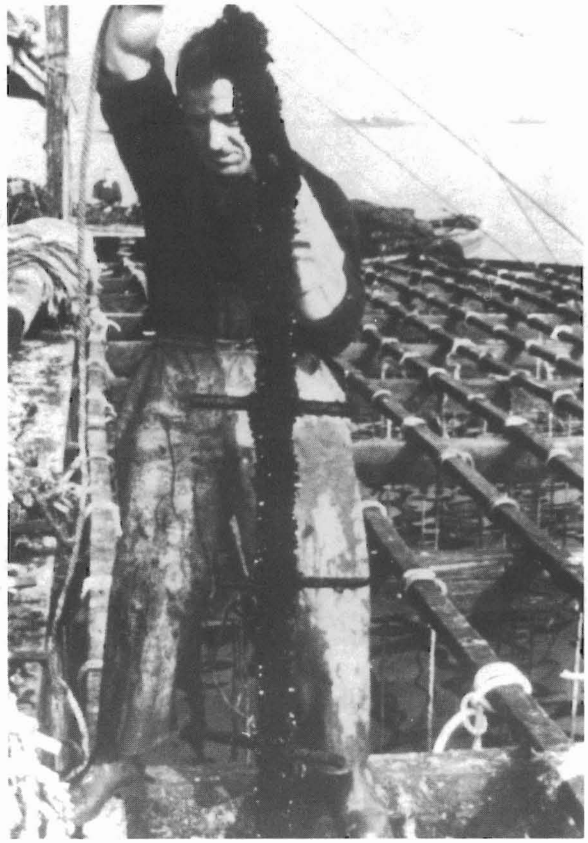


Figure 7
A rope with settlement of mussels, showing wooden pegs between the strands of the rope to keep the clumps of mussels from sliding down.

more important than high temperature effects that cause the seed collected on the ropes in the spring and the fall and transplanted to the ropes, to reach the same size at the end of the first winter (Bardach et al., 1972; Figueras, 1989).

Harvesting—Mussels of commercial size are available throughout the year and can be harvested at any time, but the main harvest is from October to March when their market demand is high and their condition is the best. Meat weights can approach 50% of total wet weight when the mussels are in the best condition. When a large percentage of mussels is close to spawning or have just done so, harvesting should wait until they are in better condition (Figueras, 1989). The mean production per m^2 of raft area averages 130 kg and for an entire raft 20 to 100 t, with a mean value of around 47 t. Such values are highly variable and depend on size of the rafts (Perez Camacho et al., 1991). Production is also about 10 kg of mussels per meter of rope (Figueras, 1989). Annual losses (natural mortality and handling) have been estimated at 15% (SOMEGA, 1975). Recent results show that the natural mortality in mussel experimentally cultured is around 5% (Robledo[2]).

To harvest mussels, farmers use cranes to raise the ropes to their boats, where the mussels are separated and graded by rubbing them over grids of iron bars. They are then washed to clean off small mussels, silt, empty shells, ascidians, and other unwanted organisms. Any mussels too small for market are wrapped on new ropes for further growing. The marketable mussels are then packed in nylon bags and taken to depuration stations (Fig. 9). Women usually do this work. Each handles about 200 kg of mussels every 8 hours. Mussel production has increased sharply from 1956 to 1987 (Table 1).

[2] Robledo, J. A. F. Biologist, Instituto de Investigaciones Marinas CSIC, Vigo, Eduardo Cabello, 6, 36208, Vigo, Spain. Personal commun., Aug. 1992.

Figure 8
Mussel cluster disintegration with a cylindrical machine, and hand rubbing in a steel screen for size sorting (for market or further growth).

Figure 9
Net bags with mussels destined for the depuration station.

Maintenance—Each raft normally holds three types of ropes: Those for collecting seed, those with growing mussels, and those with marketable mussels. Thus growers maintain continuous production from their rafts (Figueras, 1989). Since the mussels grow faster near the water surface, some growers periodically invert the ropes to produce mussels of about equal size (Lutz et al., 1991). In rafts with only one central float, the equilibrium of the raft is altered when farmers raise ropes for thinning or harvesting, and they have to put containers filled with water on the appropriate area of the framework to avoid tilting it. A large number of mussel seed and fouling organisms attach to the floats and, as they grow, the weight of the raft increases. So, occasionally, farmers have to clean the floats. It is easiest when the raft is nearly empty and floats higher, leaving many mussels and fouling organisms exposed to air where they die and are easy to remove. For major repairs of the framework or floats, farmers take the rafts to shipyards or factories. A medium-sized wooden raft has a life span of 10–15 years, while modern fiberglass rafts last considerably longer (Lutz et al., 1991). Rafts range in age from 0 to 30 years, with an average of about 8 years (Perez Camacho et al., 1991).

Numbers of Fishermen in Different Time Periods

The mussel industry in the Galician region is mainly composed of family businesses. In 1975, SOMEGA estimated an average of 3.4 rafts per owner; only a few had more than 10 units. Currently, the mean number of rafts per owner is 1.5 and their operation is still by families (MAR, 1991). A few big companies have more than 12 rafts with permanent or temporary employees; their operation is similar to any capitalist enterprise. Some have their own depuration stations or work closely with depuration stations and canning factories (Nunez and Castro, 1990). Another middle-sized group has from 5 to 12 rafts. These owners work on the rafts but also hire extra help. Finally, the last and most numerous group is comprised of families who have from 1 to 5 rafts. They do all the work themselves and alternate the operation of their rafts with finfishing or land farming (Nunez and Castro, 1990).

All members of the family work at culturing the mussels. Andreu (1976) stated that, with the exception of the heavy work, women do all the work. One man and three women are needed for the operation of a typical raft. The size of the Spanish mussel industry in terms of manpower is not easy to estimate because there are many connected activities, and several companies that work with mussels also deal with other species of mollusks. In 1958, 450 people worked directly in the raft operation. By 1985, in the Galician region, about 7,000 people farmed mussels and 3,000 more engaged in related industries such as depuration plants, cooking and freezing factories, canneries, transport, and shipyards constructing mussel rafts and machinery.

With the growth of the industry, mussel farming associations have appeared. The largest one, called OPMAR, has 80% of the proprietaries and has 1,664 members. Currently, there are about 2,000 proprietaries with working families (MAR, 1991).

Government Regulations for Mussel Farming

The first regulation regarding mussel culture in rafts was approved in 1961 and, in 1974, the first plan for the installation of rafts in the rias was implemented. A regulation for collecting mussels from the natural beds was established in 1969 and 1970. It prevents farmers from gathering mussels from January to July, and establishes a minimum size of 50 mm. The regulation on the gathering of mussel seed to supply the rafts is minimal: Mussel farmers must notify the marine authorities about the quantities and localities of the mussel seed they gather (SOMEGA, 1975).

The raft areas for culturing mussels are owned and controlled by the government and leased to operators for a small fee. The lease is for 10 years and is renewable, but it may be terminated by the government without notice. To obtain permission to put a raft in the bay, the grower has to apply to the Ministry of Agriculture, Fisheries, and Food. Until 1988, the most important aspects related to the installation of rafts were navigation, public works, national defense, and recreation. It was also important that the site chosen was not subject to gross sewage pollution and that the planned increase in production would not saturate the market. The operator does not have to pay anything for the concession, but does have to pay anchorage dues to the Ministry of Public Works, and the industrial contribution is similar to all other factories and shops.

Legally, there is no limitation to the number of rafts that a single owner can have moored, but recently the number of rafts has been limited by new regulations that consider the water quality and carrying capacity in the area. In 1989 a water quality regulation for the culture of bivalve mollusks was established and, during 1990, a regulation for the location of rafts was approved. Then in 1991 the regulation for the reorganization of the culture areas in the Galician region was established (Tecnologia Ambiental, S. A., 1991). With the integration of Spain into the European Economic Community (EEC), the regulations for water quality for mollusk culture have been made consistent with the EEC directives.

Government Regulations for Selling Mussels

In 1964 the first law for mollusk quality and healthiness was approved. This law established that inspection, water quality control, and healthiness of the mollusk has to be coordinated by an official team of inspectors consisting of representatives from governmental institutions denominated: General Direction of Salubrity, General Direction of Marine Fishing, and the Instituto Espanol de Oceanografia. Water and sanitary laboratories were constructed and the classification of littoral areas, based on their water quality, was established. The law states that all fishermen and fish farmers need a license to market mollusks, and that all bivalve mollusks taken from natural beds and those reared in rafts or hatcheries must be purified in an authorized depuration station before their sale. The law for molluscan depuration was modified in 1970, adding specifications on the type, size, and color of package, and the use of an official sanitary procedure was also included to obtain a better control for the national and export markets (SOMEGA, 1975). The last modification was made in 1985.

For export, the first regulations and those from the Commerce Ministry (Ministerio de Gobernacion y Comercio) are applicable dispositions that were approved in 1956. Other regulations to prevent the sale of mollusks contaminated with biotoxins were approved in 1986 and 1987, and the areas for the location of rafts to avoid the effects of biotoxins in the Galician region were established in 1990. Finally, the regulations for the exchange of mollusks were established in 1986.

Depuration

In 1964 the first depuration station with a daily capacity of 15 t of mussels was opened in the Galician region (DEMARSA, 1965). By 1975, 20 depuration stations were registered in that region, and at present there are 54. The depuration stations obtain water from submarine collectors located at a depth of about 3 m beneath the surface at low tide, or from coastal wells. The water usually is treated with sodium hypochlorite (1–3‰) or is injected with chlorine gas. The chlorinated water is allowed to cascade down a series of three or more large concrete tanks to remove the excess chlorine before being pumped into indoor or outdoor storage basins used for depurating the mussels. The use of ozonation is not extensive, and there is no ultraviolet sterilization.

The mussels are held in trays or baskets placed on raised concrete platforms in the basins at a density of 30 kg/m. Each basket contains 17 kg of mussels. For bacteriological safety, it is sufficient to keep the mussels 24 hours in the basins, but to have a wide safety margin they are kept there for at least 48 hours. Afterward, the mussels are packed in bags manually or automatically in quantities of 1, 2, 5, 10, and 15 kg; the bags are closed with a metal wire turned tightly with a special spiral-shafted hook. Depurated mussels are then packed in yellow net bags provided with the authorized health certification. The mussels without depuration are packaged in red bags. The colors are officially mandated, as is their use.

Red Tides

Considering the high fertility of the rias, one wonders whether excessive blooms of certain dinoflagellates would not, once in a while, render the mussels dangerous to consumers. However, such phenomena are rare. Nevertheless, Spanish biologists watch continuously to determine if a dinoflagellate bloom is present in the rias. The Department of Health also constantly screens mussels from different rias to determine whether they have PSP (paralytic shellfish poison) or DSP (diarrhetic shellfish poison). If either condition is detected, the entire ria or section of it is immediately closed to harvesting of all mollusks that grow there.

Distribution and Marketing

The growers take the mussels in their boats directly to the depuration plants or to canning factories. There are two mussel markets in the region: The fresh market before depuration and the processed market. Larger quantities of mussels are marketed fresh, but the canning market has grown since 1984 (Tables 2, 3). The mechanization of handling is minimal, to reduce damage to mussel shells and thereby enhance the shelf life of the mussels during transportation. In the warm season, refrigerated trucks are used to transport the mus-

Table 2
Marketing of fresh mussels from 1984 to 1989 (MAR, 1991).

	Amount marketed (t)		
Year	National	Export	Totals
1984	70,000	22,000	92,000
1985	75,000	21,000	96,000
1986	76,500	19,000	95,500
1987	85,000	24,000	109,000
1988	70,000	28,000	98,000
1989	68,000	27,000	95,000

Table 3
Marketing of mussels in the canning industry from 1984 to 1989 (MAR, 1991).

	Amount marketed (t)		
Year	National	Export	Totals
1984	28,000	3,800	31,800
1985	36,200	4,600	40,800
1986	47,000	4,200	51,200
1987	56,500	4,300	60,800
1988	63,000	5,100	68,100
1989	69,000	6,000	75,000

sels. Ice bars are held with the mussels on the longer trips to maintain a high humidity. Sometimes, mussels for the Spanish market are transported by train. The farmer sells the mussels to the depuration station. The station sells the mussels to central markets, from which they are sold to restaurants and consumers. The remaining mussels are sent to markets outside Spain (Nunez and Castro, 1990).

The processed market deals with mussel meat, which can be processed for cannery, demiconserve, and freezing. The mussels that go directly to the canneries are those having the poorest quality and size (Nunez and Castro, 1990). They are prepared by frying or boiling and then covered with various sauces. They can be served in many ways. The cans (about 115 g) are sealed, cooked (sterilized) in an autoclave, labeled, and packed in shipping cases for worldwide distribution. The marketing of canned mussels more than doubled from 1984 to 1989 (Table 3).

Mussel markets have been changing. At the beginning of mussel farming in Spain, mussel consumption was limited, but today national consumption is more than 100,000 t, mainly as fresh mussels (MAR, 1991). In 1984 the distribution of mussels was 40% for the fresh market (76% of these for the local market and 24% for export), 50% for canning (the quantity of canned mussels consumed in the home market was 89% and the remaining 11% was exported), and 10% for freezing. In recent years, about 60% of mussels have been for the fresh market and 40% for canning. The frozen portion has been increasing and is estimated at 15,000 t per year (MAR, 1991). Exports are mainly to Italy, France, and Germany.

Costs and Prices

According to Andreu (1976), the cost of a floating raft is governed by its size and the materials used. In 1948 a single raft with all the equipment including 800 ropes cost around 83,000 pesetas (P125 = US$1). In 1958 its cost reached P250,000; of this, P150,000 were for carpentry, P21,000 for the chain and anchorage, P65,000 for the spart grass ropes, and P14,000 for the boat and incidentals. In 1976 the cost was from P1,500,000 to P2,000,000 (Figueras, 1976), and currently their cost, considering the equipment, is about P15,000,000.

The price of the fresh mussels in 1951 was P2.0–2.5/kg and, in 1958, P3.5–3.75/kg (Veiga, 1958). In 1976 the price directly from the rafts was from 7.5 to 9.1 pesetas per kg, and in the first sale the price reached 15–20 pesetas per kg. The price for the consumer was about P30/kg (Andreu, 1976). Currently, the price for the consumer is around P180/kg. These prices are very low when compared with prices for other kinds of shellfish or meat. The profits for a family has been calculated at about 25% of their total production sold (MAR, 1991).

Future of the Fishery

During the past 45 years, Spain's mussel production has become the second highest in the world. However, several biological, technological, and socioeconomic factors must be considered and studied to maintain and increase the production.

In the past few years, there has not been a substantial increase in the number of rafts and, while the sizes of rafts and rope size have grown, total production of mussels has not grown. Thus a production limit is approaching and probably the number of rafts should be controlled (Porta, 1984). To increase production, new suitable areas must be found. The loss occurring from predation by starfish, crabs, and fishes is not substantial, and the parasites, *Mytilicola intestinalis* (copepod) and *Marteilia* sp. (protozoa), have not really affected mussel production. Nevertheless, a permanent program is needed to study mussel mortalities, prevalences and incidences of parasites, and condition index. Transplants of mussels without assurance that they are healthy should not be made. A special program is needed for the maintenance of the water quality, because an increase in pollution of the water could not only increase the prevalence of parasites but also the levels of toxic substances such as heavy metals. In this sense, the control program of red tides must go on, and it is important to evaluate the impact of mussel culture on the environment and on other commercial species.

To regulate and control the use of seed for culture, information is needed on distribution and collection of mussel larvae, availability of seed, and such related information as places where larvae set, amount of seed available, and effect of the gathering on the natural populations and their recuperative capacities. Mussel production can be affected by low salinity, which kills mussels on the upper 0.5–1 m of the ropes, and by winter storms which can damage and even sink the rafts (Lutz et al., 1991). These problems can be reduced by continuous monitoring of water salinity and with the use of better rafts.

Mussel culture could be improved with the use of new materials for raft construction including floats and ropes, design of sinkable rafts that will permit the culture in rough waters while increasing the culture surface (Figueras and Figueras, 1990), improving the system which prevents mussel clusters from sliding down the ropes, and better machinery for harvesting, transporting, and processing. However, any technological improvement must take into account the total value to the fishermen in the region, because one of the reasons mussel culture is successful is the low operational cost due to use of many family members. With high mechanization, much employment will be lost. On the other hand, Spanish participation in the EEC will promote an additional pressure for changes in socioeconomic structure. Heretofore, the marketing structure has not allowed families to set prices. Only through a better group organization would it be possible to change this market structure and give families more control of market prices.

Oyster Fishery

Production of the flat oyster, *Ostrea edulis*, in Spain is limited. Fishermen land only about 500 t a year (Xunta de Galicia, 1990a). They obtain oysters mainly from rias in the Galician region through the culture or maintenance of imported stocks in rafts (Gabin et al., 1990). The old natural oyster beds have been depleted. Some residual natural populations occur in some parts of the rias of Arosa, Vigo, Pontevedra, Ortigueira, and near San Cibran in the North of Galicia (Fig. 1).

Habitat Description

The natural habitat of flat oysters is subtidal; few grow intertidally. They prefer clean waters that are rich in oxygen and have weak currents. Their larvae require hard substrata such as shells for settlement. Optimum temperatures are from 15° to 20°C and salinities above 26‰ (Bardach et al., 1972; Xunta de Galicia, 1990a). Natural conditions in the rias were ideal for large oyster populations, but the massive mining of shells to supply the animal food industry degraded the beds (Andreu and Figueras, 1966). In addition, reduction in water quality in coastal areas due to urban, seaport, and industrial development adversely affected the natural oyster habitats (Pazo, 1987). On the other hand, water quality and conditions for suspended culture is adequate, and today the culture or growing of oysters is carried out on floating rafts.

Associated Species and Predators

Several species are associated with oysters, including algae, *Ulva* sp. and *Enteromorpha* sp.; ascidians, *Phallusia mamillata* and *Ascidiella aspersa*; other bivalves such as *Anomia ephippium*, and the tube worms, *Pomatoceros triqueter* and *Polydora* sp., that produce extensive damage to oyster shells. The most important predators are the starfish, *Marthasterias glacialis*, *A. rubens*, and *Asterina gibbosa*, and the gastropod *Nassa* sp. (Garcia del Cid, 1954). The blue mussel is another associate, and its culture has had a negative influence on oyster production. According to Andreu (1973), mussel culture negatively affects oysters by 1) softening the bottom, 2) filtering great quantities of oyster larvae, and 3) reducing the water circulation in rias that helps to cleanse the bottom. Heretofore, the most important enemies for oyster culture have been the protozoan parasites *Marteilia refrigens* and *Bonamia ostreae*. They have been associated with the largest mortalities that have occurred in cultured populations in Spain and the rest of Europe (Figueras, 1991).

History of the Fishery

The first evidence of eating oysters in Spain comes from the earliest natives of the Galician region called "Castrenos," who left large deposits of oyster shells, or "concheiros," in the fourth century B.C. (De La Pena[1]). These "concheiros" also appeared in the first century A.D. near the Roman villages (DEMARSA, 1965). According to Ferreira (1988), in the 10th century, it was documented that a noble family donated properties, which included "ostrarias" (name of the oyster beds in those times), to the ecclesiastical authorities. The same author noted that in the 13th century, oysters were consumed fresh in cities and monasteries, and the oyster fishermen or "farmers" were called "ostreiros." In the 16th century, oysters were consumed in sauces. According to Gondar (1983), in that century, the miter of Compostela, in the Galician region, regulated oyster harvests to obtain a continuous supply of them for his court. By this time, some villages of the Galician rias exported oysters and other shellfish to the Kingdom of Castilla in the center of the peninsula and to Asturias in the north of Spain. Through the 18th century, in the ria de Vigo, the natural oyster populations were heavily fished to supply the monarchy. In 1706, near Carril in the ria de Arosa, ships were chartered to take oysters to other areas of Spain (Ferreira, 1988). According to Andreu and Arte (1955), the ordinances of the Pontevedra Province in 1768 referenced the existence of abundant natural oyster beds in the rias of Arosa, Pontevedra, and Vigo. By this time, Cornide (1778) stated the heavy fishing on the natural oyster populations could deplete them. However, the exploitation continued without controls. Labrada (1804), in his economic description of the Galician Kingdom, mentioned that the Carril village women sold shellfish collected by the men in the city of Santiago and the village of Padron. According to Andreu (1962), the fishing in the middle of the 19th century became more intense, and from 1869 to 1870, Paz Graells, an oyster specialist, first reviewed the oyster fishery in the north and northeast of Spain, where the most important natural oyster production areas were. He reported a large decline in the natural beds. The situation was associated with the supplying of oyster stocks to restore the French oyster industry in the middle of the 19th century (Andreu, 1962; Madariaga de la Campa, 1969). The view by Graells led to the Central Commission of Fishing establishing two oyster parks in 1874, importing oysters from France, and using French technology. The results were negative, however, in part because the localities selected for the culture installations were poor and, as a result, both parks were closed in 1884 (Andreu, 1962).

The success of oyster culture in France and the adequate natural conditions for oyster culture in Spain encouraged private investors to try oyster culture (Andreu, 1962). Dean (1893) related that oyster culture in Santander (north of the Iberian Peninsula) used cages, which were arranged in rows in a sheltered part of the harbor. These cages were elevated about 1 m above the bottom and were rarely exposed even at low tide. These early trials were abandoned because the salinity was too high and there were no natural oyster beds.

Fishing the existing natural beds continued, and they further declined. For example, near San Simon in the ria de Vigo, around 30 million oysters were harvested in 1935, while only 10 years later only 7 million were harvested, and after 1952 the bed had been practically depleted (Andreu, 1962). According to Madariaga de la Campa (1969), in 1922, nearly 3.5 million oyster seed were imported from France for grow out. However, interruptions in oyster seed importation, the Spanish civil war, and the subsequent prohibition of oyster seed exports from France prevented success. From 1953 to 1959, Sanchez (1936, 1944, 1951, 1952, 1954) conducted trials to obtain oyster spat on artificial collectors, and the Instituto de Investigaciones Pesqueras (CSIC) also carried out studies from 1953 to 1959 to protect and reestablish natural oyster beds in the Galician Region. However, the difficulty of obtaining oyster seed from the natural beds, and problems with local shellfishermen led to the failure of these projects (Andreu, 1962).

By the 1960's, natural populations of oysters were so small that oyster fishing was unprofitable (Pazo, 1987). At that time, several attempts were made to restore the remaining natural oyster beds. They featured installing several collectors similar to those used in Britanny, France, in an experimental park near Villajuan in the ria de Arosa (roofing tiles were secured by a central pole) (Andreu, 1960, 1965a,b; Andreu and Figueras, 1968; Figueras and Andreu, 1968).

At the beginning of the 1970's, one park for oyster culture was established in the ria of Ortigueira. The oysters were maintained in cases (Fig. 10), and tile roof collectors (Fig. 11) were used to collect oyster spat. In 1980 the park had about 20 t as brood stock, but afterward only around 8 t (Guerra, 1985). The reduction was caused by high mortalities attributed to the parasite *Bonamia ostrae*. In 1979 a hatchery for the semi-indusrial production of oyster and clams seed was constructed. In 1981 oysters from this hatchery were distributed to various localities in the Galician rias, and their growth was monitored (Guerra, 1985). Currently, the operation continues, and the results are promising but the supply of seed is small, and the parasites *Mortellia refrigens* and *B. ostreae* are present. By the end of the 1970's and beginning of the 1980's, about 300 rafts were used for oyster culture; they held from 70 to 100 million oysters which came as seed mainly from French Britanny. However, high mortalities were observed, and, between 1975 and 1976, about 70% of the oysters in the Galician region were lost (Pardellas, 1982). Consequently, in 1981, the importation of seed from France was prohibited (Perez Camacho and Roman, 1985). By 1987 the number of rafts for oyster culture had decreased to 137. Now the culture activities have been reduced to growing imported oysters from medium size or temporarily storing commercial sized imported oysters for immediate marketing. Research continues on the natural collection of oyster seed and its production in hatcheries.

Several authors have tried to explain the failure in the growth of oyster culture in the region during the past century. One was Dean (1893), who stated that Spain's long coastline permitted the local demand to be satisfied without need of artificial methods. In addition, the difficulty of transporting oysters into the interior of the country discouraged the development of regions where culture could otherwise have become profitable. On the other hand, Figueras (1970) stated that one possible explanation for the failure of oyster culture in Spain was that the flat oyster had never been a popular food in Spain and he pointed out that "in the Louvre Museum can be seen only one picture by the Spanish painter Nunez de Villavicencio (1600–1700) "Los comedores de mejillon" ('mussel eaters'), but there are many paintings of the French school in which oysters appear."

Culture

As noted, the establishment and growth of oyster culture has been minimal. The first trials consisted of the adaptation of French culture technology without success. Afterward, floating rafts like those used for mussel culture, were used for oyster culture. The method consisted of the manual attachment of medium-sized oysters (around 5 cm) to ropes (1 cm diameter) with cement (Fig. 12). Women workers attached two or three oysters every 10–15 cm (Figueras, 1970; Perez Camacho and Roman, 1985). During an 8-hour day, 12 women could handle 800- 1,000 kg of oysters (20–30 units depending on their size). Workers hung the ropes from rafts and periodically raised them

Figure 10
Oyster culture cases in a Galician intertidal area in the 1970's.

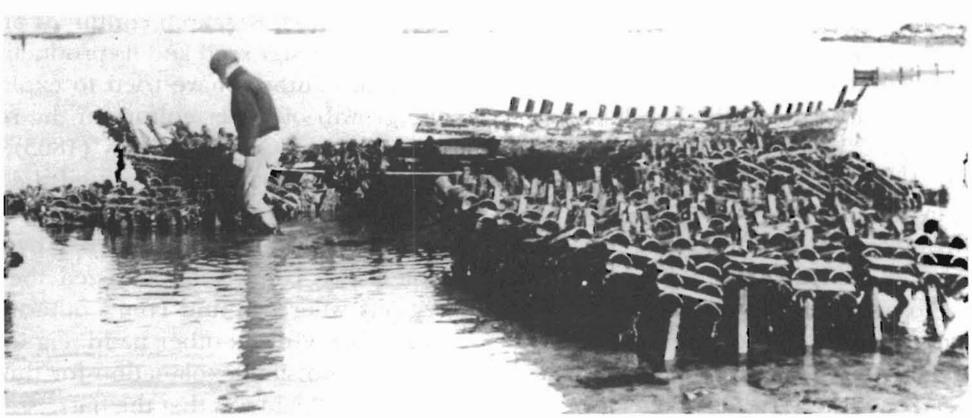


Figure 11
Roof tile collectors for oyster seed in the Galician intertidal area in the 1970's.

to clean the oysters of seaweeds and mussel seed. They harvested the oysters when they attained commercial size of 8 cm after 9 or 10 months (Figueras, 1970).

Currently, relatively few oysters are hung from ropes. Instead most are grown in plastic baskets hung from the rafts. As they grow, the oysters are thinned out. Farmers harvest them when they attain commercial size and take them to depuration stations. All the seed and the medium-sized oysters used are imported from Italy, Greece, Egypt, England, and other countries.

Seed Collection

Government institutions (Conselleria de Agricultura Pesca y Alimentacion), such as the Ribadeo station, locally called "park" in the ria of the same name, collect natural oyster seed. They use the French method of roof tiles covered with a layer of lime. The lime layer makes it easy to remove oysters when 2–4 cm long (about 6–8 months after setting). Each collector usually consists of 8 roof tiles held together with a central wood pole. Its height is about 1.25 m, and, to avoid predators of seed oysters and the accumulation of sediment, the first tile is about 20 cm above the bottom. The collectors are distributed over an intertidal area covering about 4,000 m^2 in straight lines. This institution also conducts trials, using plastic materials for seed collection. Imported seed stocks from Italy, Greece, and other parts of the world have been used. The larvae are fed until they reach metamorphosis and then are placed with plastic collectors (PVC) on which they settle. When the oysters reach 5–10 mm in length, they are taken to the rafts to grow (Guerra, 1985, Xunta de Galicia, 1990a).

Harvesting

Fishermen used to gather oysters from natural beds by hand and with hand dredges. Some years ago, a special dredge made of steel was designed. Locally called a "rastro," it was shaped like a rectangle (1.25 × 0.3 m) and provided with teeth on its lower bar. The dredge scraped across the bottom surface and had a net bag (2.0 × 1.25m) to hold the oysters. It was towed from a boat powered by a motor at least 50 hp in size (Arnaiz and De Coo, 1977). Currently, all the oysters are obtained from the rafts as oystering on the remaining natural beds is prohibited.

Regulations

As noted above, the first records describing regulations for harvesting oysters are from the 16th century (Gondar, 1983). Around 1923 and in 1935 other regulations appeared, but without success (Navaz y Sanz,

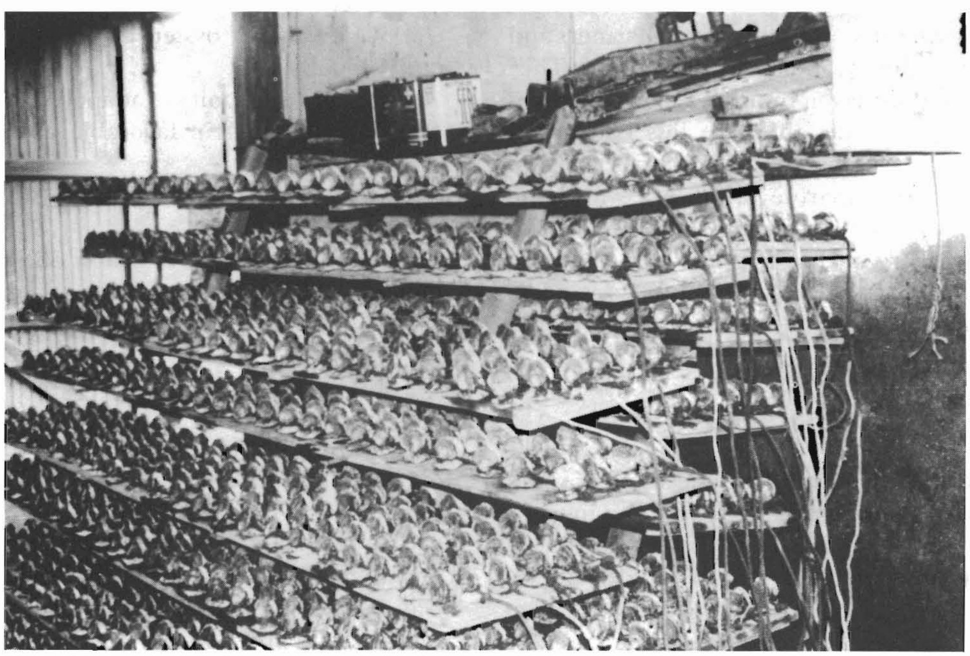


Figure 12
Ropes with attached oysters for the Galician area floating rafts in the 1970's.

1942). In 1981, oyster imports from France were prohibited because of the diseases there. The modern regulation of the oyster fishery was not approved until 1964. It established that all fishermen and fish farmers needed a license to market mollusks, and that all bivalve mollusks gathered from natural beds and those reared in rafts or hatcheries must be purified in an authorized depuration station before sale. The regulation for molluscan depuration was modified in 1970 and 1985, adding specifications on the use of an official sanitary label to obtain a better control for the market (SOMEGA, 1975; Tecnologia Ambiental, 1991). In 1984 a regional regulation about inspection of fishing, collection of shellfishes, and aquaculture were approved. In 1989 the regulation on water quality for molluscan culture was established. Other regulations to prevent the sale of mollusks contaminated with biotoxins were approved in 1986 and 1987, and in 1990 areas to place rafts in the Galician region were established to control the effects of biotoxins.

Socioeconomic Aspects

One of the main factors causing the disappearance of natural oyster beds was continuous harvesting without any action to enhance abundance or to protect the environment. This situation has been associated with poor education of fishermen, called "mariscadores," who gather oysters (Pazo, 1987). A related problem is the diversity of types of people who gather oysters. These include people who usually fish for sardines, cephalopods, crustaceans, and other fishes; farmers and fishermen's wives or family, and industrial workers. They work only part time gathering bivalves. As this activity is considered only a sideline, they are less concerned about conserving the resource. Intermediaries, who are unrelated to fishing or marine farming, control the market prices. Both situations favor negative actions or responses in the fishery, such as taking mollusks during the closed season, taking undersized mollusks, and keeping the shellfishermen poor (Gonzalez, 1980).

Depuration

Oysters, like other bivalve mollusks destined for the fresh market, must be depurated. They are put in cases in depuration tanks that are filled with chlorinated water. The maximum weight/m^2 authorized is 30 kg, and the depuration period is at least 42 hours. The oysters are then packed in wood or plastic cases in quantities of 12, 25, 50, and 100 individuals. Each package has an authorized label, on which the depuration date and the shelf life of 5 days are printed. The oysters, chilled on ice, are trucked to market.

Market

All the oysters are shipped to local markets and large Spanish cities, mainly Madrid and Barcelona, where they are distributed to supermarkets, hotels, and restaurants. The oysters are maintained in temperatures from 3° to 10°C. They are usually consumed fresh and eaten on the half-shell (Pardellas, 1982)

Future of Fishery

The protozoan parasites *M. refrigens* and *B. ostreae* constitute a major problem for European flat oyster culture (Montes, 1991; Figueras, 1991). France, the largest oyster producer, has introduced culture of the Japanese oyster, *Crassostrea gigas*, which is not susceptible to these parasites. Currently, their oyster production is mainly of this species, and production of flat oysters is small. Spain has tried to prevent the introduction of these parasites by limiting the culture of imported stocks. Any projection of the future of oystering in Spain must address the following points:

1) Protection of the remaining natural oysters and oyster beds and the quality of their environment (bottom and water),

2) Improvement of techniques for collecting natural seed and growing it in protected areas,

3) Improvement of hatchery and nursery techniques to obtain native oysters for repopulation of the natural oyster beds,

4) Culturing of oysters in areas free of *M. refrigens* and *B. ostreae*,

5) Continued studies of adaptation of imported stocks (free of parasites) in favorable areas in the Galician region,

6) Research studies to control *B. ostreae* and *M. refrigens* present in flat oysters,

7) Prevention of introduction of oysters or any other mollusks unless they are guaranteed to be free of parasites,

8) Establishment of a genetic improvement program for oysters,

9) Establishment of training programs for oyster fishermen and culturists, and

10) Improved culture technology through use of new materials and modalities in areas where the incidence of parasites is minimal.

Currently, Japanese oyster stocks have been imported, and their adaptation to the natural conditions in the Galician region is under study. These studies must go on, but with special care in all aspects related to the introduction of parasites and diseases. Finally, a balance should be established between the collection and culture of mollusks in the Galicia region, which permits their protection, restoration, and use.

Cockle Fishery

The cockle, *Cerastoderma edule*, is harvested mainly from natural beds; there is little culture of them. Current production is about 1,300 t per year (Xunta de Galicia, 1990b), about 90% of which is from the Galician bays (Aguirre, 1973). The cockle is locally known as "berberecho" or "croque" and is valued for its fast growth, capacity to survive in changing environments, and its economic value.

Habitat Description

The natural habitat of the cockle is sandy beaches or sandy and muddy bottoms (Figueras, 1956), at depths up to 10 m (Ramonell, 1985). The euryhaline character of cockles permits their distribution in river mouths and estuaries (Fig. 1).

Associated Species and Predators

Several species of bivalve mollusks occur in cockle beds, especially *Scrobicularia plana, Venerupis pullastra, V. decussata*, and *Loripes lacteus*. The main predators of cockles are the crab, *C. maenas*; starfish, *Asteria rubens*; and flatfish, *Solea* sp.

History of the Fishery

The first records describing cockle fishing also describe associated fishing for oysters. In the 16th century, people from Portugal and other areas came to the ria de Arosa near Cambados to gather oysters, mussels, clams, and cockles (Ferreira, 1988). Since then, mollusk fishing in the Galician region has been mainly for flat oysters, but possibly, during the years of heavy fishing for oysters, cockles and other bivalves may have been gathered. Until the beginning of the present century, no specific references on the abundant cockle and clam beds in the rias of Galicia appeared (Gutierrez de Velasco, 1964). Since then, some quantitative data about cockles have been published. In the ria de Pontevedra their density reached 7,500 individuals per m^2 (Lozano, 1948), while in the ria de Muros y Noya their density reached 2,250 (Gutierrez de Velasco, 1964). Fishermen sold the cockles to canneries. In 1949, in the ria de Vigo, cockle production was around 3,200 t, but it declined after that (Figueras, 1956). During 1955, a substantial mortality of bivalve mollusks, including cockles, was associated with heavy rains (Figueras, 1957). Until this year, most cockle production was from the rias de Vigo, Arosa, and Muros y Noya. From 1962 to 1964, the highest production was from the rias de Muros y Noya and totalled about 3,800 t in 1963 (Gutierrez de Velasco, 1964).

Commercial cockle production obtained in the rias and processed by the cannery factories of Arosa and Muros y Noya from 1945 to 1963 ranged from 200 to 5,307 t (Table 4) (Gutierrez de Velasco, 1964). Cockle production in the ria de Muros y Noya was around 2,500 t in the 1970's but, by the beginning of the 1980's, production decreased to less than 1,000 t (Quiroga et al., 1980). These data show that cockles can be overfished if their resource is not managed. Production from 1985 to 1988 in all the Galician region increased from 359 to 1,687 t (IUEDG, 1990), but if one looks at only production in the ria de Muros y Noya in the 1970's, production actually declined (Xunta de Galicia, 1990b). Thus the history of the cockle fishery has followed the same pattern of other mollusks in the region, i.e., a large reduction in supply from heavy fishing and an uncertain future.

Harvesting

Fishermen collect cockles in two ways: By boat or by walking on the beaches at low tide and feeling for them with their hands or with rudimentary shovels, which are modified agriculture implements (Gutierrez de Velasco, 1964).

Shovel types include the "sacho," a short curved triangular shovel which has a blade 16 × 24 cm and a handle about 90 cm long; the "legon," which is similar to the first but flat for more efficiency; the "sacha," a rectangular flat shovel 20 × 15 cm, with 35 cm handle; the "rastrillo," a typical rake (usually for agricultural use), 20 cm wide, and with a large handle; the "rastro," one of the common tools, a triangular structure of 1 m × 75 cm wide, with teeth on its bottom edge that support a net bag, to hold the cockles; "gancha," a metal rake with short teeth; and, finally, the "rano," a rake with large teeth. The walking collection of cockles has been done mainly by women. Around 1964, each har-

Table 4
Commercial production of cockles from rias, processed by the canneries of Arosa, Muros, and Noya from 1945 to 1963 (Gutierrez, 1964).

Year	Production (t)	Year	Production (t)
1945	200	1958	4,058
1953	499	1959	1,697
1954	1,887	1960	1,492
1955	282	1961	2,983
1956	909	1962	5,307
1957	1,614	1963	2,940

vester or "mariscador" obtained about 50 kg of cockles of commercial size in a day.

The other collection method, using a boat with or without a motor, is done at high tide or in subtidal areas (Fig. 13). "Rastros," "ranos," and "ganchas" are towed from the boats (Arnaiz and De Coo, 1977). Each boat fisherman can gather 100–150 kg of cockles a day (Gutierrez de Velasco, 1964). Currently, cockle fishing is still done mainly by women, and the tools used are the same as in early times (Figs. 14, 15, and 16).

Culture Methods

The first culturing of cockles was carried out in protected areas with clean, fine sand, which were called "parks." The seed was collected from natural beds, taken to the parks, and distributed at densities up to 400 individuals/m^2. Periodically, it was necessary to clean the parks of crabs and mud. The seed, growing individuals, and adults are distributed in different areas of the park. Average cockle production is about 2 kg/m^2.

Social Aspects and Regulation

The great increase in mollusk harvests which intensified at the beginning of this century, led to exhaustion of the oyster beds, the improvement of collection tools, the rise in the demand for other bivalve mollusks as foods, and growth of the cannery industry (IUEDG, 1989). The composition of the fishermen was diverse as it included temporary workers from farming, fishermen's wives or family, and industry. This favored unmanaged exploitation, and the cannery industry, depuration stations, and intermediaries controlled the market, favoring dependence of fishermen on them and limiting their profits. According to Gutierrez de Velasco (1964), the uncontrolled collection of cockles occasionally saturated the market, which limited harvests and lowered prices. In 1959 a glutted market forced the fishermen to return cockles to the beds. In addition, confrontations between walking harvesters and boat harvesters were frequent, because boat harvests were more efficient and larger, producing larger incomes for boat fishermen.

To organize the fishery, fishermen's associations, called "Cofradias de Pescadores," were established in the 1940's in an attempt to regulate fishing by limiting the quantities of cockles collected by each fisherman. However, many new harvesters increased the problems of distributing the resource equally. Finally, a harvester license, called a "carnet de mariscador," was required. It was issued only to fisherman and their families, and to poor people designated by the local government (Gutierrez de Velasco, 1964). In 1964 the regulation defining mollusk quality and purity was approved. It

Figure 13
Cockle harvest boats at the pier in the ria de Vigo in the 1970's.

Figure 14
A woman collecting cockles with the "rastrillo" in a park culture of cockles and clams in Carril (ria de Arosa).

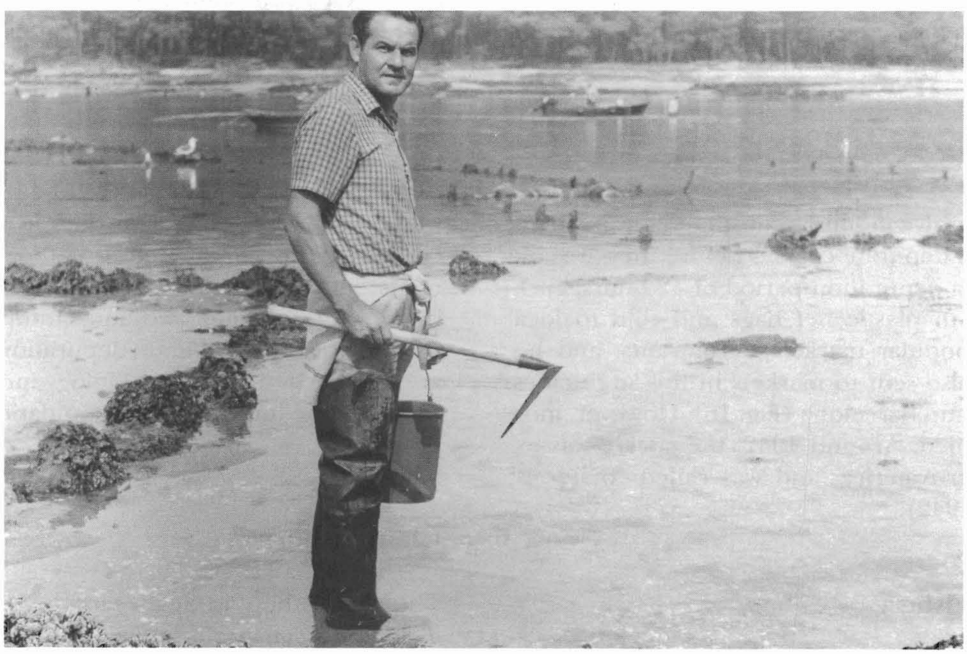


Figure 15
A man with a "legon" that will be used to remove the sand and to collect cockles and clams in Carril (ria de Arosa).

Figure 16
"Gancha" implement used to collect cockles from the boats. Rianxo, ria de Arosa.

also controls the distribution of harvester licenses. Other regulations were approved later, as mentioned in the sections on mussel and oyster fisheries. Currently, the open season for cockle fishing is from March to October, and the minimum size allowed is 25 mm.

Market

As with all the bivalve mollusks consumed raw in Spain, it is necessary to depurate cockles before they are sold (Fig. 17). After a depuration period of 42 hours, cockles are packed in plastic net bags and sold to local supermarkets, popular markets, restaurants, and hotels. Some are also sent to markets in the large cities, such as Madrid and Barcelona (Fig. 18). However, most cockles are canned. Around 1942, the cockle was exported to South America, and was called "oyster B" (Navaz y Sanz, 1942).

Future of the Fishery

Since the increase in fishing for cockles at the beginning of this century, the harvesting gear, methods, and social structure of the harvesters (mariscadores) has scarcely changed. However, the decline in abundance of the cockles and the integration of Spain into the European Economic Community (EEC) will require modernization of the fishery. Improvements in the fishermen's association and fishing regulations will help to train the fishermen and control prices. Fishing gear and resource conservation must also improve. Aquaculture technology must improve through the creation of large production parks and the development of new technologies and tools. In the future, the construction of hatcheries and nurseries will be necessary. In addition, maintenance of clean water is imperative, so the cockles are not threatened by pathogens and contaminants. The European tendency is to control water quality for all the fishing and aquaculture activities, more than to create and operate depuration stations. Studies are also needed on cockle biology including reproduction, genetic improvement, population dynamics, and pathology.

Clam Fishery

The clam fishery in Spain targets three main species: *Tapes decussata*, locally known as "almeja fina"; *Venerupis pullastra*, called "almeja babosa"; and *V. rhomboideus*, called "almeja rubia." Their total production has been estimated at 2,000 t (Xunta de Galicia, 1990c). All come from harvests of natural beds in the Galician bays. Other production areas are Cadiz and Huelva in the

Figure 17
Cockles, loose and in bags, before transportation to a depuration station.

Figure 18
Trucks used to transport cockles and clams in the 1970's.

south of Spain. *T. semidecussata* is produced in Andalucia. Currently, there are few aquaculture activities of any size. All the clams are valued in the region, and *V. pullastra* is considered as a traditional food.

Habitat

Clams live on the sandy beaches of the rias. *T. decussata* is buried in the sand from 15–20 cm from the middle of the intertidal zone to a depth of a few meters. *V. pullastra* lives in sand, gravel, or mud bottoms, usually from the low tide mark to a depth of 40 m. *V. rhomboideus* is found from the intertidal zone to a depth of 200 m (Navaz y Sanz, 1942; Vilela, 1950; Ramonell, 1985).

Associated Species and Predators

Other bivalves growing with the three clams are *Venerupis aurea, Diosinia exoleta,* and *Tellina incarnata.* Their main predators are the crab, *C. maenas*; the starfishes *A. rubens* and *M. glacialis*; gastropods, *Natica* sp.; and birds, *Larus* sp. (Vilela, 1950; Aguirre, 1973; Campos and Saavedra, 1990). An individual *C. maenas* (6.5 cm width) can consume 5–6 clams per day (Campos and Saavedra, 1990). Recently, protozoan Perkinsus-like infections have been found in *T. decussata* in the ria de Vigo (Robledo et al., 1992).

History of the Fishery

The 16th century records of mollusk fishing and consumption are mainly about the flat oyster and only rarely about clams, but they do mention the marketing of clams in Portugal and other places (Ferreira, 1988). According to Navaz y Sanz (1942), the beginning of the intensive fishing for clams was in 1926 and 1927. Digging was indiscriminate as fishermen used prohibited tools and took clams of all sizes. Near San Simon, in the ria de Vigo, fishermen found one natural clam population and depleted it in a short time. The fishermen sold cases of clams weighing 54 kg for only 5 pesetas. Later, when competition increased, the price was 30 pesetas. In 1935 clam fishing was regulated and the quantity of clams each fisherman was allowed to take during each low tide was 14 kg, and the season was closed from May to October. Then, near San Simon, there were 6,130 walking harvesters and 1,480 others using boats.

Despite the large clam harvests, their repopulation is rapid. Lozano (1948) pointed out that populations of *T. decussata* and *V. pullastra* in the ria del Burgo recovered in less than a year from 1–5 to 30–50 clams per m^2. Production of clams from 1927 to 1953 in the ria de Vigo ranged from 28,719 to 652,890 kg (Table 5). Around 1956, clam production in the Galician region was about 60% of national production (Alvarez, 1960). At that time, 250 boats fished for bivalves near San Simon in the ria de Vigo; each harvested from 10 to 12 kg of *V. pullastra* per day (2,500 kg in all). The season was from October to March. In areas nearest to the mouth of the bay about 60 boats obtained 3,000 kg per day. These differences were associated with the great mortality that occurred in the inner part of the ria de Vigo, due to heavy rains that produced a rapid drop in salinity (Figueras, 1956). In the ensuing years, clam production has been variable, and statistical data on total production is sparse. In the ria de Noya, production rose from 1965 to 1969, later declined, and increased again in 1974, 1979, and 1980. However, the steady fishing of the natural populations led to a reduction in natural populations, a diversification of the species collected to include *V. rhomboideus*, and a search of new collecting areas. From 1985 to 1986, production of the clams *V. pullastra* and *V. rhomboideus* was around 1,700 t. Production of *T. deccusata* was reduced, showing the effect of the intensive exploitation (Fernandez and Pardellas, 1986). Currently, production is about 2,000 t.

Harvesting

In the Galician region, fishermen harvest clams either by walking the intertidal areas and using special hand shovels or from boats. The capacity of the small boats is about 1 t, while the large boats range up to 12 t. Some are propelled with oars or outboard motors (Quiroga et al., 1980). Various collection tools are used, including the "rastro" and the "rano" (Arnaiz and De Coo, 1977). The closed season is from March to October, and the minimum size allowed for *T. decussata* and *V. rhomboideus* is 30 mm, while for *V. pullastra* it is 25 mm.

Culture Methods

Some Galician areas have protected bottoms called "parks" for the extensive culture of clams (Fig. 19).

Table 5
Production of clams in the ria de Vigo from 1927 to 1953 (Alvarez, 1960).

Year	Production (t)	Year	Production (t)
1927	153	1943	386
1933	29	1948	653
1938	87	1953	81

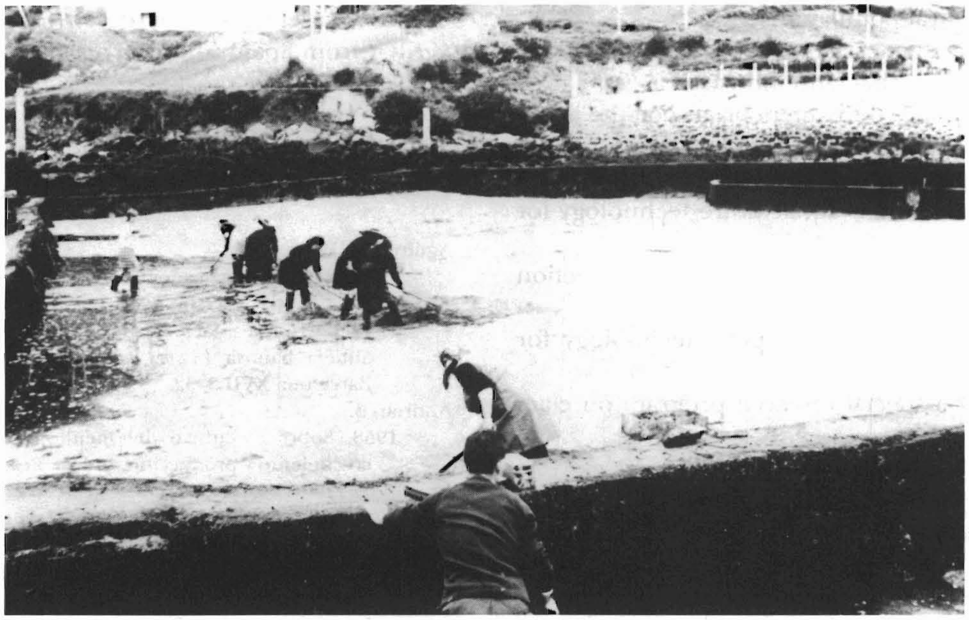


Figure 19
A park for culturing clams in Carril (ria de Arosa) in the 1970's.

Farmers obtain seed from their own parks or from the natural clam populations in the spring. They dig the clam seed with sand using a small shovel, pass it through a sieve to retain the seed, take it to their parks, and spread it in densities of about 800 clams per m^2. They can also dig adult clams from seaport areas and spread them in their parks. Periodically, they have to clean their parks of predators and mud. In 1987 the Japanese clam, *Venerupis semidecussata*, was introduced, and several trials have been made growing them in plastic baskets hung on floating rafts and burying the clams in the sand of protected parks, to study their adaptation to the environmental conditions in the rias (Guerra et al., 1990). Near Ribadeo, there is one hatchery for the semi-industrial production of *T. decussata*. It produces seed which is transferred to protected parks for growth.

Depuration and Marketing

Fishermen bring their clams to the depuration stations where they are held in pools for at least 42 hours. The clams are then packed in net bags of 0.5, 1, and 2 kg, and are destined to be canned or eaten fresh. They are sold in local supermarkets, popular markets, hotels, and restaurants, including those in Madrid and Barcelona. They are transported by refrigerated trucks that maintain temperatures of 3°–10°C; the clams have a shelf life of 5 days. Prices vary according to their abundance in the market. However, as an approximation, in 1985 the price was about P99/kg. Currently, the price for fresh clams is about P2,000/kg for *T. decussata*, P1,200/kg for *V. pullastra*, and P900 kg for *V. rhomboideus*. Canned clams are prepared with vinegar and various sauces. In the Galician region, the most popular meal with clams is "ameixas a marineira" (clams in mariner sauce). The clams are open in salted water and cooked with a special sauce (onions, garlic, parsley, bread rind, and white wine).

Future of the Fishery

The history of shellfishing in the Galician region shows that the mollusks were improperly managed. First one species was depleted and then another. First to be depleted was the oyster; after that the digging of cockles and clams began, and as *T. decussata* became scarcer, the digging of *V. rhomboideus* began. Currently, the populations of the other commercial bivalves are declining. Besides heavy fishing, clams declined because pollution increased and the seaports and urban areas grew, degrading the clams' habitat. The future of the molluscan fisheries in the Galician bays must be planned as an integral reorganization program to include the following aspects:

1) Reorganization of the harvesters and the market structure to improve the responsibility and profits of the fishermen,

2) Creation of protected areas for the recovery and growth of the natural populations,

3) Creation of a general program for treatment of wastewater from the urban and industrial areas,

4) Establishment of a permanent project on the population dynamics of the clams, and biological studies, especially, to improve genetics,

5) Development of new aquaculture technology for the hatchery, nursery, and grow-out phases,

6) Diffusion of a popular program for the protection and consumption of bivalve mollusks,

7) Incorporation of the European technology for these fisheries, and

8) Creation of a special research program on clam pathology.

Pectinid Fishery

Three major species are of commercial importance in Spain: *Pecten maximus*, called "vieira"; *Chlamys varia*, called "zamburina"; and *Chlamys opercularis*, called "volandeira." Historically, *P. maximus* has represented the Christian symbol of the travel of the apostle St. James through Spain, and this symbol is in all the churches of the Galician region. When oyster production at the beginning of the 20th century declined, the pectinids were gathered as an oyster substitute, and their populations were substantially reduced (Navaz y Sanz, 1942). The pectinids are fished in the mouth of the rias where the main natural beds are (Fig. 1). Currently, harvests are regulated; the closed season is from March to October and the minimum sizes allowed for *P. maximus* is 10 cm, and 4 cm for both *Chlamys* species. Their production is relatively small; during 1986 production of *P. maximus* was 44,497 kg (IUEDG, 1989). Fishermen use the same implements to gather them as they use for clams and cockles.

Currently, *P. maximus* is cultured on a small scale in the Galician region by attaching small ones (10 cm) to ropes in floating rafts. Farmers obtain the small scallops from the natural beds and attach about 150 scallops to each rope.

The future of this fishery will depend on the growth of new aquaculture technology and application of the protective measures noted for the other bivalve fisheries in the region.

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Fisheries and Farming of Important Marine Bivalves in Portugal

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ABSTRACT

Oysters and other bivalves have been used as food since the earliest eras in Portugal. The two most important commercial oysters are the flat oyster, *Ostrea edulis,* and Portuguese oyster, *Crassostrea angulata.* The flat oyster declined after 1900 and was replaced in importance by the Portuguese oyster and more recently by clams. Pollution was the main reason for decline of the oyster industry. Oyster culture began in the 1950's, and production rose to 10,000 t in 1964. About 2,000 people full-time and 10,000 others, for 8–9 months of the year, cultured oysters. Production fell afterward and now is 150 t/year. The most important clam cultured is *Ruditapes decussatus.* Fishermen gather seed, 5–10 mm long, from natural beds and plant them in private plots. In 1.5–2 years, the clams attain market size of at least 25 mm. Fishermen gather some other bivalves along the shores at low tide for sale. Bivalves have to be depurated in areas where the quality is below Portuguese law or EEC regulations. Off the north coast, a fleet of boats harvests bivalves found at depths from 10–50 m. The most important are white clams, *Spisula* sp.; golden carpet clam, *Venerupis aurea*; razor clams, *Ensis* sp.; and striped venus, *Venus gallina.* In 1989, fishermen landed 1,800 t of clams. At least 80% of *R. decussatus* and white clams are exported to Spain and France. Bivalves in Portugal are sold fresh, refrigerated, frozen, and in many preprepared and precooked ways.

Introduction

The harvesting of bivalve mollusks has been an important component of Portugal's fisheries since ancient times. A multipurpose fleet of boats in all the fishing harbors of the 850 km Portuguese coast (Fig. 1) has harvested several species of bivalves, mainly the flat oyster, *Ostrea edulis* (until the first decade of this century), and nowadays several species of clams, cockles, and mussels. Fishermen have also harvested bivalves by raking and by hand along the shores.

Most bivalves have been gathered and cultured in estuaries, lagoons, and "rias" (deltaic complexes). However, manufacturing industries, agriculture, tourist facilities, and other activities are now intruding into them, and the capacity to produce bivalves is being lost entirely in the Tejo estuary and partially in some others. In areas that have good environments, including good water quality, bivalve production is good.

History of the Fisheries

Oysters and other bivalves have been used as food since the earliest eras in Portugal. Many shell deposits composed of different bivalves (but mostly oysters), bones, ceramics, and charcoal have been found in prehistoric sites along the Portuguese coast. The deposits, called "concheiros" and located near the Tejo estuary ("Muge"), the Sado estuary ("Herdade do Portancho"), and in Algarve ("Ponte de Marcil") (Fig. 1), date from the last Bronze Era, about the 9th century B.C.[1]

During the Roman occupation of Portugal, from about 140 B.C. to 400 A.D., oysters were an important food. Eating oysters was probably common in the Middle

[1] Information was collected from manuscripts provided by Rui Monteiro, a former senior researcher of Instituto de Biologia Maritima, and from a booklet published by the Centro Historico das Universidades de Lisboa/Museu Arqueologico de Setubal.

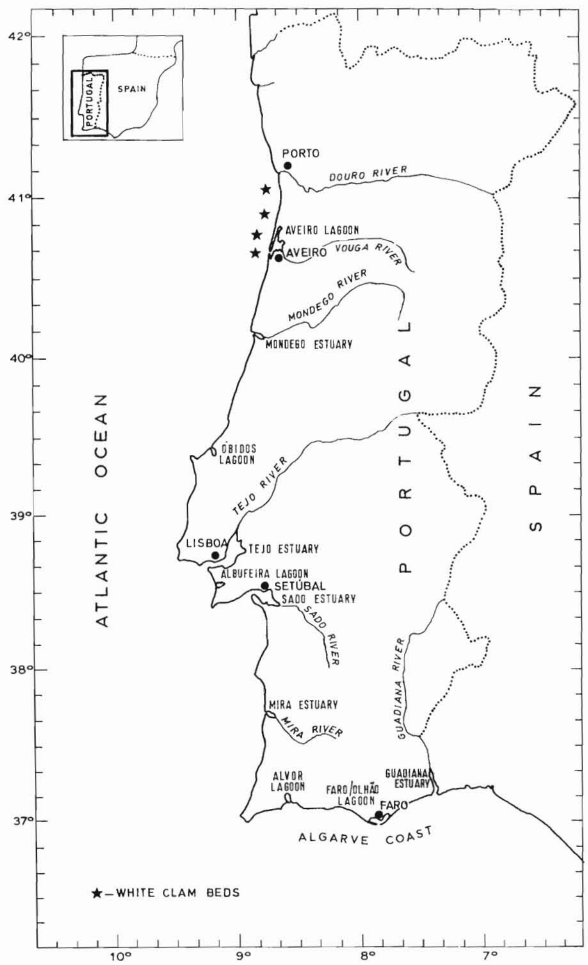

Figure 1
The principal areas where bivalves are produced in Portugal.

East and spread to other provinces of the Roman Empire, including Portugal. The Romans harvested oysters from natural beds in the two main estuaries, the Tejo and the Sado. In the Sado estuary, ruins of a Roman city, named "Cetobriga," still exist. They include tanks for salting fish, which shows that the Sado estuary was a big center for fisheries, salt production, fish processing, and probably oyster production. The products were sent to other provinces of the Empire.

Oysters and other bivalves always have had great importance in coastal communities. For example, in 1682, responding to a request of local fishermen from the north, a special law for the protection of bivalve beds was passed as bivalves were a main food and provided employment for people. The nutritive value of oysters was also recognized centuries ago and, in 1731, Francisco F. Henriques, a Portuguese physician, described the advantages of eating oysters which included the treatment of several diseases.

In the 19th century, oysters continued to be an important food and were sold in several coastal markets. In 1867, a private company signed a contract with the government to lease a large area of public oyster beds on the south shore of the Tejo estuary. The company made commitments to: 1) Preserve and enlarge the oyster beds, 2) create new oyster beds in the most appropriate sites, and 3) develop methods for fattening and improving the quality of oysters for export.

During a visit to Portugal in 1891, Bashford Dean, biology instructor at Columbia College in New York City, described the oyster near Lisbon: "The harbor of Lisbon is a miniature sea, a mile or more in width and half a dozen miles long. The southern shore of this sea, opposite the city, is the home of the oyster . . . . Those oyster beds have not merely furnished the Lisbon market, but have been the center of active export" (Dean, 1893). Oyster culture did not then exist in the Tejo estuary. In addition, the quality of oysters was poor, and almost the entire production was exported to France and England where they had to be rebedded for a while to improve their quality before being eaten.

Although some measures were taken after the 1860's to improve oyster quality in the natural beds, oyster culture has been practiced only since the middle of the 20th century. In 1868 the first law was passed to regulate fishing in the natural oyster beds. It specified that 1) Oysters could not be harvested from 1 April to 31 September, covering the spawning season, 2) the minimum size of oyster that could be harvested was 5 cm, and 3) oysters in intertidal zones could be gathered only by hand.

After that, several measures were passed covering special situations to protect human health. In 1895 the first "Regulation law for the oyster industry, oyster parks, and oyster culture" appeared. In 1923 the first "Sanitary regulation law for oyster industry" was passed. In 1953 the government built the first depuration plant for oysters in the Tejo estuary, and in 1972 it published the new "Regulation law for oyster industry."

Despite those measures, the Portuguese oyster industry remained undeveloped and was limited to the gathering of available oysters. Nevertheless, this was a substantial fishery and, throughout history, thousands of families have gathered thousands of tons of oysters from hundreds of hectares of beds in the Tejo and Sado estuaries and the Algarve lagoons, nearly all for export.

In 1890 the flat oyster, which constituted 85% of landings, was the most important bivalve landed, but by 1910 its share had fallen to only 40%. Its decline was caused by overharvesting and silting of the beds in river mouths and lagoons. To prevent further declines, the government, in October 1895, banned any harvesting for 3 years in "rivers, rias, ports, lagoons, and bays of the kingdom." The rule was included in Article 5 of the law that established rules for "oyster beds exploitation, oyster culture, and oyster deposits in public property waters."

Shellfish Harvesting and Culture

Oysters

According to Nobre (1940) and Vilela (1975), there are four oyster species along the Portuguese coast: flat oyster; Portuguese oyster, *Crassostrea angulata;* stone oyster, *Ostrea stentina*; and *O. cochlear.* Only the first two species are economically important. The importance of the flat oyster declined after 1900 and was gradually replaced in the next decades by the Portuguese oyster and more recently by clams. Nowadays, the flat oyster is relatively rare along the coast except for a few small natural beds in such lagoons as Lagoa de Albufeira, located between the Tejo and Sado estuaries (Leal, 1984), or those on the south coast of Portugal. Its production is limited to a few longline system units on the south coast.

Abundance of the Portuguese oyster has increased in almost all brackish water estuaries, lagoons, and rias. It can occupy areas from intertidal and subtidal zones to the deepest parts of canals, 10 m, and from river mouths to several kilometers upstream. It occurs on substrates of sand, sandy mud, silt, and shells. It tolerates a wide salinity range, even as low as 2–6‰ in winter and after heavy rains. After 1–2 months of rains, a large number of oysters in the upper parts of estuaries become affected by so-called "fresh water edema" due to osmoregulatory dysfunction. In contrast, during summer, in beds close to river mouths or inside lagoons, salinities can rise to 35–38‰ without any apparent stressing of the oyster. The temperature range in its habitat varies from a minimum of 8°–10°C in northern waters during winter to 20°–30°C in southern lagoons during summer.

During the rainy season, the water in large estuaries carries a large quantity of silt. It flocculates and settles on oyster beds, causing mud blisters in the shells of oysters as well as heavy mortalities of oyster spat.

The main oyster predators are several species of crabs (especially the green crab, *Carcinus maenas*), gastropods, sea stars, and sea birds. Oyster larvae are eaten by jellyfish.

The Portuguese oyster was formerly abundant, especially in the Tejo, Sado, Mondego, Mira, and Guadiana estuaries, as well as in the Albufeira, Obidos, and Ria de Aveiro lagoons on the west coast, and the coastal lagoons of Alvor and Faro-Olhao in the south (Fig. 1). The best habitat for producing it was the Tejo estuary. Currently, its natural beds have declined to 200–300 ha in the upper part of the Sado estuary and a few deep-water beds in the other locations.

Harvesting—Before the modernization of the oyster industry, fishermen gathered all oysters by dredging from boats or by hand while walking. They harvested flat oysters on the Algarve coast and Portuguese oysters in estuaries and lagoons by towing small dredges from sail or row boats. The old type of oyster dredge consisted of a semi-arched iron rod and a tooth bar with a single row of 10–20 teeth, each 10 cm long. Its net bag was made of leather. Fishermen towed it with a cable or a long-handled pole (Silva, 1893). They dredged mainly for flat oysters until 1910 or 1915 and then switched to Portuguese oysters. Harvesting and culturing oysters was important economically for 60–70 years until the early 1970's; 80–90% were exported. Afterward, production declined sharply (Fig. 2).

Factors Causing Industry Decline—Pollution was the main reason for decline of the oyster industry, particularly in the most productive areas (Vilela, 1975). Even in olden times, the consumption of oysters caused periodic outbreaks of human diseases in coastal communities. For example, in 1887 several such outbreaks in Lisbon were linked to oyster consumption (Monteiro, 1986). The oysters came from the north shore of the Tejo estuary which had many sewage outfalls from Lisbon. Since then, oyster harvesting along the entire shore of the Lisbon estuary has been forbidden.

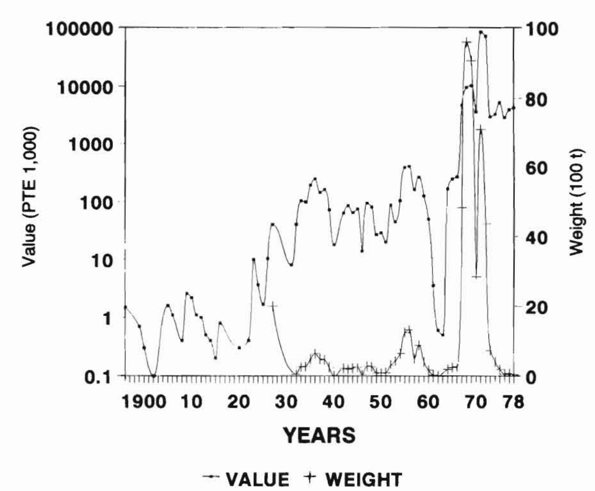

Figure 2
Production of wild oysters by value and weight, 1896–1978 (weights were not available until 1927).

Beginning in the middle of this century, large-scale manufacturing industries have developed in Portugal. A major site has been the large Setubal Peninsula, between the Tejo and Sado estuaries which have the large commercial harbors of Lisbon and Setubal, respectively. Several heavy industries, such as shipyards, steel works, chemical complexes, oil refineries, cement facilities, and paper mills have been constructed, first on the south shore of the Tejo estuary and later on the north shore of the Sado estuary. Sewage treatment facilities were inadequate or absent.

At the same time, agriculture and animal husbandry intensified, and agroindustrial facilities were built in the basins of the two estuaries. Use of fertilizers and pesticides increased. In addition, the populations of Lisbon and Setubal grew, and sewage outflows increased. As a consequence, the quality and production of oysters declined in the Tejo estuary in the early 1960's. Now the oyster fishery has ended and the old beds of Portuguese oysters have been colonized by the noncommercial *O. stentina* (Ruano, 1984). The colonization could be linked with degradation of the genetic patrimony of the intensively exploited Portuguese oyster, compared with an untouched genetic heritage of *O. stentina,* which gave it the capacity to adapt and survive in a poor environment.

The same thing happened 10 years later in the Sado estuary, where only a few natural beds remain. They cover an area of about 200 ha in its upper parts.

Additional factors besides pollution were responsible for the decline of the oyster industry:

1) The occurrence of several epizootics, namely the "oyster gill disease" (Comps et al., 1976) caused by an iridovirus, a severe disease causing extensive lesions in the gill epithelium which sharply reduced filtering capacity and killed some young and stressed animals;

2) "Foot disease," a shell disease related to the fungus *Oystracomblabe implexa* (Alderman, 1971), which is probably associated with a secondary bacterial infection. It destroys the adductor muscle. Valve movements, tight closure of the valves, water pumping, and blood circulation are reduced;

3) Several protozoan diseases, mainly caused by *Hexamita* sp., *Ansistrum* sp., and *Trichodina* sp., also affected oysters by increasing their morbidity when they were stressed by factors such as high temperatures;

4) An ineffective or absent management strategy to protect the natural beds;

5) Overharvesting and depletion of the beds by fishermen who tried to meet a strong market demand; and

6) Nonexistence of hatcheries which could have provided farmers with juvenile oysters when natural spatfalls were declining.

Culturing Oysters—In the middle of the 20th century, the Navy Ministry, which was the predecessor of the current National Institute for Fisheries Research (INIP), established the "Estacao de Biologia Maritima" (Marine Biological Station). It was there that Herculano Vilela, one of the most distinguished marine scientists of Portugal, and a few collaborators began modern oyster culture in the country. Studies were conducted on the biology, spacial and temporal distribution, reproduction, nutrition, and pathology of oysters. Rearing methods were adapted from France, first in the Tejo estuary, 1954–56, and later in the Sado estuary and Algarve lagoons, and the industry improved. According to Vilela (1951b), the methodology involved three steps: Larval attachment, spat collection, and growth.

Larval Attachment—Several types of collectors, including ceramic tiles covered by a cement mixture, chains of shells, and plastic tubes, are put in selected sites when government technicians predict that oyster larvae will set in abundance. The technicians sample the water for larvae every day.

Spat Collection—When the spat are 6–8 months old and 2–4 cm long, workers remove them from the collectors as single oysters ("destruncagem" in Portuguese) and place them in growing parks. The workers prepare the parks ahead of time by cleaning them, compacting their soil, and destroying predators and competitors. They then grade the spat by size. If the spat are large enough, they are placed directly on the ground; otherwise, they are held in wood trays ("casiers") which have net bottoms. The trays, held 20–30 cm above the bottom by wood or iron stockades, are cleaned periodically by workers.

Growth—The oysters remain in the parks until they attain commercial size, at least 5 cm long. However, if the water quality is poor and food is sparse, sometimes it is necessary to transfer them to cleaner sites with richer water to improve quality and growth. The operation, called "afinacao" (improvement), is carried out in earthern ponds with inlet and outlet water control sluices or at other appropriate sites.

As a consequence of improvements in culture methods, oyster production rose from 2,064 metric tons (t) in 1956 to a peak of 10,000 t (1 t of oysters = 33 U.S. bushels) in 1964 (Fig. 3). The overall area devoted to culturing oysters, 950 ha, was controlled by 45 concessions employing about 2,000 people full time and 10,000 others for 8–9 months/year.

In 1968, when workers produced 8,496 t of oysters, 90% were exported to France. The net profit was 85 million PTE (Portuguese escudos) (US$3 million).

Present Situation—Methods and technologies for producing natural and cultured stocks of oysters are the same as in the past. Most oyster production has been

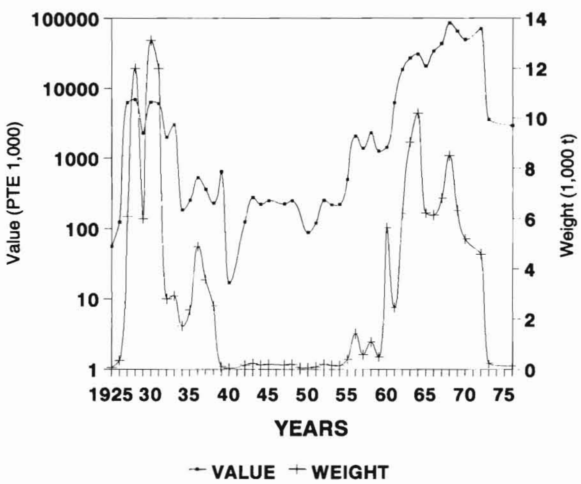

Figure 3
Production of cultivated oysters by value and weight, 1925–76.

Figure 4
Small anchoring ground in the Sado estuary, showing grading trays, rakes, and bags full of oysters.

transferred, however, from the Tejo and Sado estuaries (Fig. 4) to Algarve. In the Tejo estuary, production ended in 1972, while in the Sado estuary, production has been stable at the limit set by the government of 150 t/year during the past 3 years, but it had declined from 9,000 t/year in 1972. Fishermen rarely dredge for oysters now, as the deep-water beds are depleted. In addition, the government forbids any harvesting with dredge boats in estuaries and lagoons. In coastal waters, dredging is mainly for other bivalves and is tightly controlled to prevent conflicts between finfishermen and shellfishermen.

Fishermen have always gathered oysters in shallow water and intertidal zones with different types of rakes, forks, or other tools, and by hand. The methods are still used by a small number of fishermen and their families. In the Sado estuary, a person can gather 80–100 kg (27 kg of oysters = 1 U.S. bushel) on a low tide. The season lasts from September to April. The oysters must be transplanted to other growing sites for 6–12 months to improve their quality before being marketed.

Grooved Shell Clam

The most important clam species for culture is the grooved shell clam, *Ruditapes decussatus.* Other common names for it are "Christian clam," "fine clam," and "good clam." Farmers culture it in the Algarve lagoon systems of Ria de Faro and Ria do Alvor (Fig. 1). The lagoon's waters, which average 4 m deep, cover an area of about 20,000 ha and are protected from the sea by several sandy islands. It is connected to the sea by four main entrances or "barras." The margins of hundreds of twisted canals and small islands inside the lagoon are covered by extensive marshes. Sediment grain sizes vary from sand/mud to coarse sand. The water temperature ranges from 10° to 25°C, salinity from 33.8‰ in winter to 38‰ in summer, pH from 7.7 to 8.3, and dissolved oxygen from 140% during high tides to 60% during low tides. This is an important ecosystem, acting as a nursery for many species which stock nearby coastal shores. It is a good habitat for bivalves, especially clams, owing to high primary productivity, and they grow rapidly there.

The main predators of the grooved shell clam are the green crab; fiddler crab, *Uca tangeri*; several species of gastropods; sea stars; sparid fishes; and aquatic birds. Its main competitors are bivalves, such as the blue mussel, *Mytilus edulis*; flat and Portuguese oysters; clams, such as *Venerupis pullastra* and *V. rhomboides*; and the cockle, *Cerastoderma edule.*

Culture—Farmers collect seed at a length of 5–10 mm from natural beds. (The lack of hatcheries has been an important factor limiting a good and stable production during the past 6 years.) The seed is planted in man-made culture beds, called "viveiros," which are located in intertidal zones where clams grow best. Grooved shell clams burrow 5–15 cm in sediments. Clams <25 mm long grow 9–10 mm from March to August, the period of most rapid growth, in the culture beds. They grow slowly from September to March (GEA, 1987).

Farmers prepare the culture beds ahead of time by adding sand and gravel to the sediment to permit the transfer of food and oxygen between the water-sediment interface and the clams. This common practice promotes growth of clams especially when they are small.

The two main seasons for planting seed are March to May (using juveniles which set during the previous fall) and October to December (using juveniles which set during the previous spring). Farmers also stock their culture beds between those times if seed is available at a reasonable price.

After the seed is planted, farmers keep beds clean of macroalgae and debris and try to control predation by sea birds, green crabs, fiddler crabs, gastropods, and fish. They use gravel to hide the small clams from sea birds which seek them during low tides, and they cover the seed with nets to protect them from the other predators.

Farmers plant the seed at a density of about 1 kg/m^2. Clam growth is variable, and soon after planting their lengths vary from 5–20 mm and their densities from 200–400 $clams/m^2$. Clams in the upper layers of culture beds, especially in sloping areas, can be moved with the sediments as much as several meters by strong tidal currents during storms.

In $1^1/_2$–2 years at most, depending on the seed size used, almost all the clams have reached the legal market size, a minimum of 25 mm. However, in the best areas, the clams can reach an average length of 35 mm and sometimes 50 mm in the same period. Their final density varies from 2 to 6 kg/m^2, depending on conditions.

Farmers harvest the clams by digging in the sediment with a special knife having a large blade (Fig. 5) and then picking up the clams by hand. Afterward, the clams are washed, graded, packed in mesh bags that hold 25–35 kg each (Fig. 6), and then sent to markets or depuration plants. Bivalves have to be depurated if produced in areas where the quality does not reach the values imposed by Portuguese law or EEC regulations (MPN [most probable number] <300 fecal coliforms/ 100 ml of meat and intervalvar liquid). Currently, all production from the two main estuaries, the Tejo and Sado, as well as Aveiro, Obidos, and Faro-Olhao lagoons must be depurated. Before the clams leave the plants for market, government technicians check their sanitary condition. If clams meet the standard, the technicians then attach a sanitary certificate to the batches of clams. The bivalves that fishermen gather from wild beds, usually in smaller quantities, are handled the same way.

Clam Mortalities—During the summer (hot) season of 1983, several farmers had substantial losses of clams that were nearly market size. Such losses have continued. Several research teams found that a protozooan parasite killed the clams. It was diagnosed first in 1984 as "Dermo" (Chagot et al., 1986b; Ruano and Cachola, 1986), later as *Perkinsus marinus*, and finally as a new species, *Perkinsus atlanticus* (Azevedo, 1989).

The high prevalence of this pathogen in clam populations may be attributed to several factors, such as degraded muddy sediments, high clam densities, absence of any physical barriers between different culture beds, and animal transfers between them. In addition, year-round temperatures above 12°C and salinities above 15‰ contribute to its development.

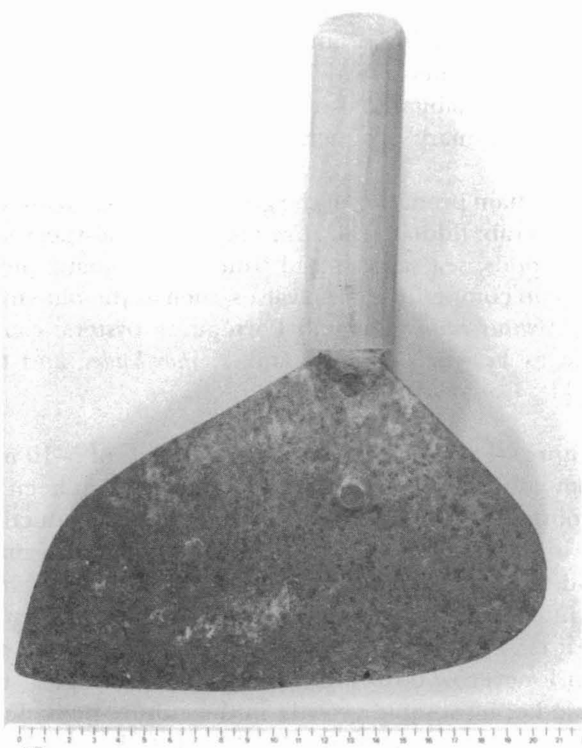

Figure 5
Knife with special shape for harvesting clams by hand.

Figure 6
Fishermen washing and grading grooved shell clams.

Other pathogens have also been observed. For instance, Vilela (1951a) described several agents, specifically a new *Haplosporidium* species, which he identified as *Haplosporidium tapetis*. Later, Chagot et al. (1986b) classified it as *Minchinia tapetis*. The prevalence of the diseases in the grooved shell clam in 1986 and 1987 are summarized in Figure 7.

Production of the grooved shell clam (Fig. 8) has varied in this century, but its economic and social importance to local communities has always remained high. Currently, the total area used for producing the clams is about 1,000 ha, which the government leased to farmers. The number of culture beds is about 1,500, total production of clams is about 4,000 t/year (1 t of clams = about 25 U.S. bushels), and the number of people directly involved with the culture beds is about 1,500.

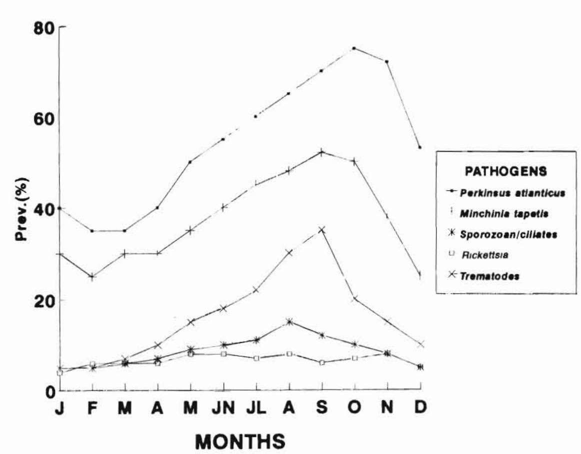

Figure 7
Prevalence of the most important pathogens of the groove shell clam at Faro-Olhao lagoon in 1987 (Ruano, 1989).

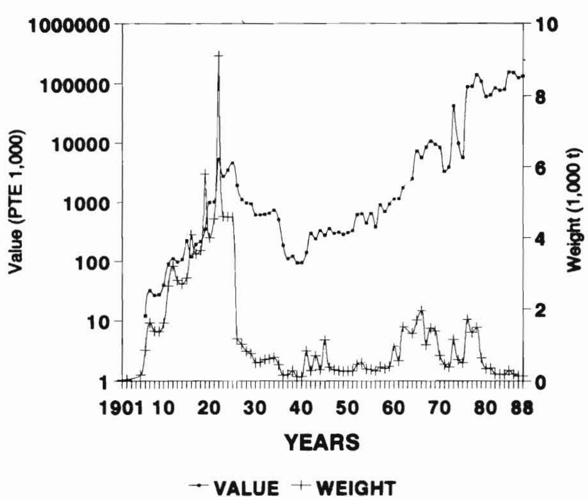

Figure 8
Production of grooved shell clams by value and weight, 1900–87.

Deep-water Clams

Along the northern coast, north of Aveiro, a fleet of boats having capacities of 477 GTR and 1,116 hp dredges for clams (Fig. 9). Their targets are typical thalassic bivalves, found at depths from 10–50 m. Currently, the most important are the white clams, *Spisula solida* and *S. solidissima*; golden carpet clam, *Venerupis aurea*; razor clams, *Ensis* sp.; and striped venus, *Venus gallina*. Some minor species are also taken. The catch rate of the boats is 2,000 g of white clams in a 5-minute tow (Sobral and Jorge, 1989). However, for the same species and same effort on the Algarve coast, the catch rate is only 10–700 g (Monteiro, 1985). In 1989 they landed about 1,800 t of clams, worth PTE214 million (US$1.4 million) (Sobral, 1990) (Fig. 10).

Other Bivalves

Fishermen gather several other bivalve species, such as mussels, cockles, and the wedge clam, *Donax* sp., along the shores at low tide. It is an old and common activity called "Marisqueio" (shellfish gathering) (Fig. 11, 12, 13) and takes place in the shallow waters of estuaries,

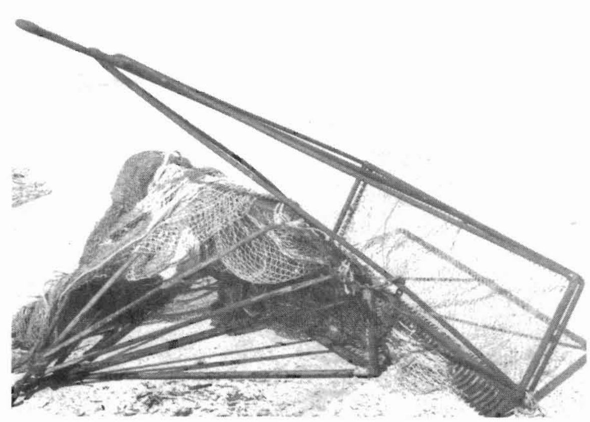

Figure 9
Dredges used for gathering white clams, razor clams, and other bivalves in deep waters (10–30 m).

lagoons, and rias. Prime areas are on the south coast, mainly in the Faro-Olhao and Alvor lagoons. Additional centers are Ria de Aveiro, a deltaic complex of the Vouga River 60 km south of Porto City, Obidos and Albufeira lagoons, and the Mondego, Tejo, Sado, Mira, and Guadiana estuaries.

Pulling dredges while walking in 0.8–1.2 m of water during low tides is another common way of harvesting species, such as the wedge clam, on sandy grounds. It is done in lagoons and along the coast.

Another method uses a small dredge from a boat. Crews of two anchor the boats and dredge the surrounding area. To retrieve the dredges, they use manual winches or long-handled poles. During a single tide, a crew can harvest 400–500 kg of clams, cockles, or mus-

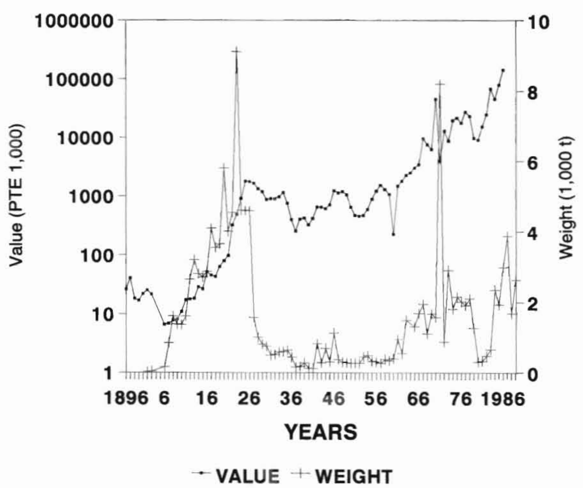

Figure 10
Production of the cockle, mussel, and minor species of clams by value and weight, 1886–1988.

Figure 11
Fishermen gathering bivalves during low tide from the shore of a lagoon.

Figure 12
A fisherman carries his rake and basket of bivalves.

Figure 13
A drag or rake for gathering cockles and mussels.

sels (36 kg of clams or cockles or 27 kg of mussels = 1 U.S. bushel).

Environmental Issues

The gathering of clams and especially the dredging of grounds alters the upper layers of sediments where several crustacean and finfish species obtain food and shelter during phases of their life cycles. As a consequence, shellfishing is closely regulated by specific Administrative Rules issued by the government. They cover the harvesting season, location of grounds, minimum size for each species, size and power of the boats, as well as characteristics of the dredges for the different species (Governmental Laws 438/72, 11/80, and 43/87).

Public Health

For protection of human health, the government has published several laws and Administrative Rules since the middle of the 1800's regarding oyster production. The same procedure has been followed more recently for the other bivalves because several people had gastrointestinal infections after eating them. Consumption of cockles from Mondego estuary in October of 1975 is one example. Under law 11/80 and others such as EEC Directives 923/79 and 432/91, Governmental Law 261/89, Administrative Rule 980-A/89, and the "Water Quality Act" 74/90, the government has legal tools to control the entire production of shellfish, from the beds to consumers, to protect human health. A special program for permanent control and monitoring of Portuguese coastal waters is conducted by the INIP for early detection and quantification of toxic microalgae to avoid human intoxications.

After harvesting bivalves, workers grade and wash them to remove sand, mud, algae, and other detritus. After that, while in boats or ashore, they pack the bivalves in mesh bags and sell them to local dealers who resell them to local markets or export them after certificaton of their quality. Bivalves gathered locally from wild stocks, usually in smaller quantities, are handled the same way.

Landings Statistics

Bivalve landings have been reported as an independent sector of fisheries statistics for nearly a century. However, their real importance has been neglected, and part of the production was not and still is not mentioned in official statistics. This is because fishermen harvest the clams from many small, widely distributed sites along the coast, and the people also pursue other activities, mainly finfishing and farming. All data presented are official data collected from Estatisticas das Pescas Marítimas/Estatísticas das Pescas 1886–1986.

Sales and Uses of Bivalves

At least 80% of the production of reared grooved shell clams and the white clams are exported to Spain and France. However, the national market has become increasingly important, especially in large population centers and seashore tourist areas where the clams are in demand during the summer season.

Nowadays, bivalves in Portugal are sold fresh, refrigerated, frozen, and in many preprepared or precooked ways. Other than oysters, eating raw bivalves is not popular in Portugal. The traditional recipes for cooking bivalves in shells are: 1) Slightly steamed with no condiments and 2) boiled in different sauces, mostly consisting of aromatic herbs, often with garlic, onion, and tomato, and usually with wine and olive oil. Shucked bivalves, cooked with rice or mixed with other ingredients to make the stuffing for fried or roast cakes, are also popular Portuguese cuisine.

The Future

We must restore and preserve bivalve environments that have been degraded by pollution. Public and private organizations need to be shown that bivalves require good environments so their habitats can be protected. To restore the oyster industry in the Tejo estuary and especially in the Sado estuary, the following steps must be taken: 1) All sewage must be treated; 2) the remaining beds must be restocked and protected, using some natural seed, but mainly hatchery seed; 3) oyster production must be increased in the unused areas of earthen fish ponds such as inlet and outlet canals, certain areas of water reservoirs, and even in other parts of fish ponds; and 4) oyster culture technology should be diversified, using sticks, stakes, racks, or combined methods as well as suspended devices using trays or "casiers."

Nontraditional culture systems for the flat oyster, such as long lines and suspended trays, have been tested successfully on the southern seashore and in some lagoons. In 1991, production was 15 t by one unit; six more units of similar design are projected for several sites along the Portuguese coast. Two bivalve hatcheries are under construction, and substantial quantities of oyster seed have been imported every year from France and Spain. Thus, the oyster industry seems to be improving.

The absence of bivalve hatcheries has been a great obstacle to the implementation of a sound epidemiological program to control diseases of the grooved shell clam. The open culture system used and the strong influence of environmental conditions make it difficult to control them.

Acknowledgments

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Mollusk Fisheries and Aquaculture in Italy

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ABSTRACT

Molluscan farming in Italy dates back at least 2,000 years to when the ancient Romans reared oysters, mussels, and fish. Italy was a leader in marine farming until the last century, when, except for culture of the mussel *Mytilus galloprovincialis*, its molluscan culture waned. For other species, culture techniques are recent and are limited mostly to nonindigenous species introduced in the 1980's. In southern Italy, oyster spat once were caught on bundles of branches and mussel seed on wooden panels deployed from rafts. The largest beds of scallops, *Pecten jacobaeus*, *Aequipecten opercularis*, and *Proteopecten glaber*, and clams, *Tapes decussatus*, *T. philippinarum*, *T. aureus*, and *Chamelea* (*Venus*) *gallina*, are found in the central and northern Adriatic Sea. Culturists grow most of Italy's mussels and clams in lagoons from the Po estuary to Trieste. Mussels now are grown in suspended mesh socks and constitute the highest landings of any mollusk, i.e., 175,000 t in 1992. The main species of clams harvested are *T. philippinarum* and *T. decussatus*, both produced by culture, and *C. gallina* and *Callista chione*, both landed from natural stocks. In many areas, *T. philippinarum* has colonized natural bottoms where it is harvested. Fishermen introduced the Pacific oyster, *Crassostrea gigas*, in the early 1960's, and grew them along with the native oyster, *Ostrea edulis*, but have since nearly abandoned culturing them. In the 1960's, fishermen adopted the "rapido" dredge from France which permitted the harvesting of *P. jacobaeus* in the Adriatic Sea. In the early 1980's, scallops became scarcer and culturists began to grow them on longlines. In 1989, 45,000 people were directly involved in shellfishing, 8,500 others in processing, and 16,500 in distribution and marketing. Mollusks are eaten in various ways in Italy. Molluscan production still relies heavily on fishing of natural stocks, but aquaculture will be important in the future.

Introduction

Molluscan farming in Italy dates back at least 2,000 years, to when the ancient Romans farmed oysters (Bouchon-Brandely, 1890; Dean, 1893) and fish, as can be seen in mural art of the time. Oysters, *Ostrea edulis*, from the Adriatic Sea (Fig. 1) were eaten in European capitals in the late 18th century (Fig. 2) and probably long before.

Italy was the European leader in advanced marine farming methods until the last century (Coste, 1861), and for a long time the town of Taranto was at the forefront of Italian oyster culture. During the 1870's, in the northern Adriatic Sea near Trieste, a series of 21 growing parks (10 acres each) was producing a total of 10 million European flat oysters, *Ostrea edulis*, annually. The industry did not keep abreast of foreign technological improvements and its methods became obsolete or inappropriate, except for culture of the mussel *Mytilus galloprovincialis* (Mattei and Pellizzato, 1989).

Apart from mussel culture, aquaculture techniques are recent and currently are limited mostly to nonin-

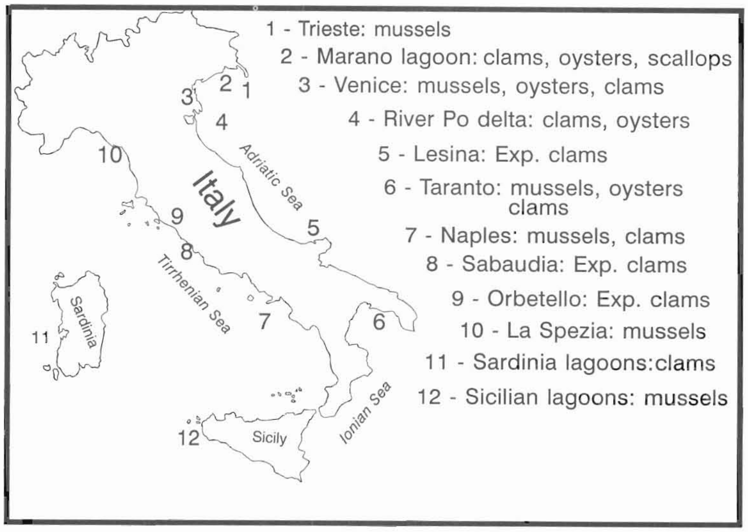

Figure 1
Italy, the surrounding seas, and the main molluscan culture areas.

digenous species introduced in the 1980's. Important areas, other than Taranto, for culture include: The Gulf of Naples (mussels, oysters, and clams); the lake areas of Sabaudia and Orbetello (experimental culture by fishermen of mussels and clams); the Gulfs of La Spezia and Trieste (mussel hanging culture); the central and northern Adriatic Sea (mussels, clams, and oysters); and Sardinia where molluscan culture is developing in lagoons around Cagliari (Fig. 1).

Most mollusks now landed, except mussels, are from natural populations which are being depleted. Current government policy is to restrict the harvesting of natural populations and to encourage the development of aquaculture enterprises.

Ancient Shellfish Culture

Mussel and oyster culture, though somewhat artisanal and empirical in its development, has been practiced in Italy from antiquity. The Romans were among the first European molluscan culturists. Their techniques are represented in detail on funeral urns from the first century B.C. that have been recovered in Puglia and the Roman countryside (Fig. 3). Over the centuries, the techniques were developed further, especially at Baia, in the embayments of Fusaro (Fig. 4) and Lucrino. The methodology has been preserved through the ages. The antique culture methods, though adopted and maintained by groups of fishermen at Naples and Taranto, have changed little over the years.

The custom of using marine organisms as food had an early origin, probably related to the maritime mercantile activities of the Phoenicians (1,200 to 64 B.C.), and it was later amplified by Hellenic colonists in the period of expansion to the islands and the peninsula to the west of their homeland (323 to 30 B.C.). It thence was transferred to the culture of imperial Rome (250 B.C.). Roman technologists perfected the methods and equipment used for harvesting from natural populations in the estuaries and sea and developed land-based systems, especially as regards culture and maintenance of mollusks, as witnessed by the remains of sophisticated facilities at Baia and Pozzuoli (cf. Gaius Plinius Secundus, Natualis Historia, 1st century B.C.). Here the landed gentry constructed the complex systems referred to as "ostrearia" for the hanging culture of oysters and possibly mussels as figured in engravings on small vitreous bottles now found in several archaeological collections. The apparent common use of mollusks and other marine animals in the diet of the residents of the Italian peninsula and the Roman colonies is documented in numerous mosaics dating from the end of the second century B.C. through the early Christian era (Solinari, 1987).

In the southern areas of Italy, oyster spat traditionally was caught on bundles of branches suspended from horizontal lines in the culture parks. The spatted branches subsequently were broken into smaller pieces and inserted into lengths of coarse grass rope that were hung vertically for oyster growout to market size. This practice continues today on a limited scale (Fig. 5).

D'Erco (1862, 1863, 1864) described in detail the culture of oysters and mussels in the northern Adriatic Sea. Oysters were cultured in shallow impoundments (claires) at Noghera near Trieste in the early and mid–1800's. Mussel seed was collected and cultured on small wooden panels deployed on rafts moored in the Laguna Veneta near Venice. D'Erco also described the traditional oyster culture methods that were still being practiced widely in the southern part of the Italian peninsula.

Ecosystems and Mollusk Fisheries

Italy has one of the highest ratios of coastline to surface area (1:43.4 km/km^2) in Europe and on this basis might be a major producer of fish and mollusks. But much of the shoreline is unsuited for molluscan culture, and production has never been able to meet domestic demand. In 1980, Italy had to import 42% of mollusks it consumed, and by 1988 this figure had risen to 56%.

The west, south, and east coasts vary substantially in shoreline types, sea bottoms, and hydrographic features. The northern Tyrrhenian coast has rocky shores with littoral bottoms alternately sandy, muddy, and stony. The southern Tyrrhenian coasts are more rocky and irregular with mostly stony bottoms. The habitat is similar along the coasts of the Ionian Sea and the southeastern Adriatic Sea. The range of tides on the coasts is about 10 cm.

The central and northern Adriatic Sea have sandy bottoms as far as the Gulf of Trieste, where they again become rocky. Extensive flat bars in the sea range in depth from 15 to 20 m, while the maximum depth in sloughs is 70 m. The Adriatic Sea receives large inputs of nutrients from the Po, Italy's longest river, and other rivers draining the south face of the Alps, and since the

Figure 2
Painting of gentry in Vienna or Budapest feasting on oysters, *Ostrea edulis*, harvested in the Adriatic Sea, 18th century.

Figure 3

The culture of oysters was a practice known to the ancient Romans, as is documented by two designs on urns from the first century B.C. The upper design is from an urn from an unknown location. The lower design is from an urn recovered at Piombino on the west coast; shape of the urn is shown at its right. Realizing the high nutritive value of oysters, the Romans fed them to the sick and convalescents (Graioni, 1975).

exchange of water is slow, its waters are more productive than other zones in the Mediterranean Sea. Fish and molluscan production are high. The largest beds of scallops, *Pecten jacobaeus*, *Aequipecten opercularis*, and *Proteopecten glaber*, and clams, *Tapes decussatus*, *Tapes philippinarum*, *Tapes aureus*, and *Chamelea* (*Venus*) *gallina*; in Italy are found there, and they produce at least 60% of Italy's mollusks. Culturists grow most of Italy's mussels and clams in lagoon areas such as Marano and Venice, from the Po estuary to Trieste. The tidal range is about 1 m.

Numbers of Fishermen and Boats

In 1989, 45,000 people were directly involved in shellfishing in Italy, with an additional 8,500 people in processing and 16,500 people in distribution and marketing. The annual economic productivity per employee was almost three times that in agriculture (54 vs. 20 million lira (L) (L1,400 = $US1 in December 1992)) and productivity was higher than in the industrial and service sectors. The total comprehensive value of this sector of the domestic economy was US$4.944 billion.

Italy now has 527 dredge boats, of which 411 work in the northern Adriatic Sea, and about 800 boats using rakes (Table 1). The sizes of boats equipped with dredges for catching mollusks such as scallops has been increasing; their mean displacement increased about 16% from 12.35 t in 1972 to 14.28 t in 1989 (Table 2). Fishermen have been modifying their boat equipment to permit them to use multifishing techniques, because fluctuations in certain Italian marine resources have been frequent and widespread. Italy now has about 7,000 boats which have combined gears for finfish and mollusks.

Fishing Equipment and Regulations

Mollusks are sought by commercial and sport fishermen who use a wide range of equipment. In intertidal and shallow zones, they harvest mollusks with rakes and knives, while in deeper water they use dredges and diving equipment.

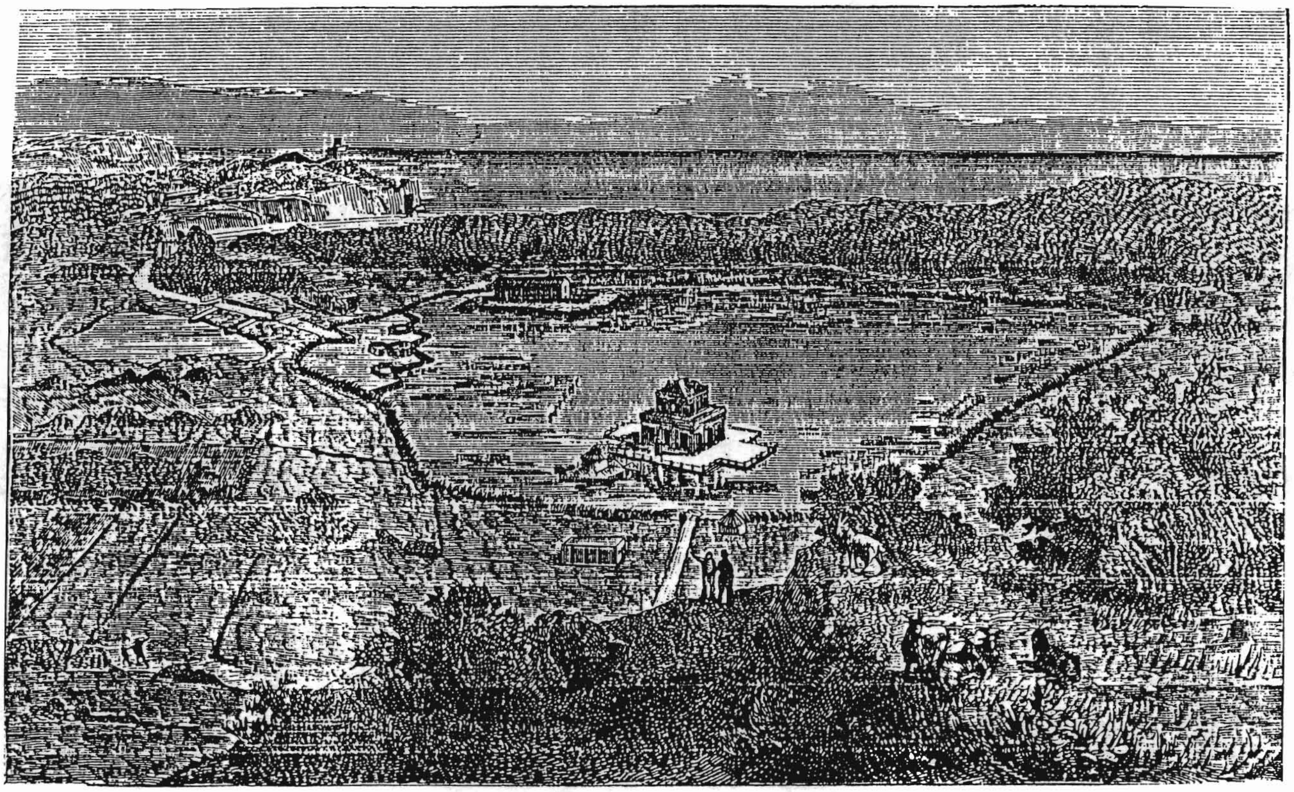

Figure 4
General view of Lake Fusaro, showing here and there the circular stake arrangements that appear to be parts of fish traps; the single and double rows of stakes, by means of which the fagots were suspended; and at one of the extremities, the labyrinths, in front of which there is a canal 2.5–3 m wide and 1.5 m deep, excavated in part in the sides of a promontory, and connecting the lake with the sea. A small lake, believed to be the ancient Cocyte, connects with this canal. In a pond or reservation, the oysters destined for sale are placed temporarily (Coste, 1861).

Table 1
Distribution of the number and gross net tonnage of Italian shellfish harvest vessels in 1989.

Area	No. of vessels	Displacement (t)
West coast (Tyrrhenian Sea)	55	367
South and southeast coasts (South Tyrrhenian Sea, Ionian Sea, southern Adriatic Sea)	61	516
Central and north Adriatic coast	411	4,337

Table 2
Italian fishing vessel characteristics, illustrating changes in horsepower and size that have occurred from 1972 to 1989.

Item	1972	1989
No. of fishing boats	18,155	18,433
Mean horsepower	50.81	102.77
Mean displacement (t)	12.35	14.28

Shallow Areas

Fishermen use a hand scrape (a blade with net behind it) to harvest mussels from rocks and wooden poles (used extensively to mark navigation channels in lagoons) and sometimes for harvesting clams, *Tapes* spp., from sediments. Its blade is 60–70 cm wide, and its handle is 3 m long. Fishermen use these hand scrapes from a small boat.

Fishermen also use a toothed rake, which ranges from 0.5 to 1.5 m wide and has a handle 1–2 m long, from a boat. They attach a rope to the rake and lash it

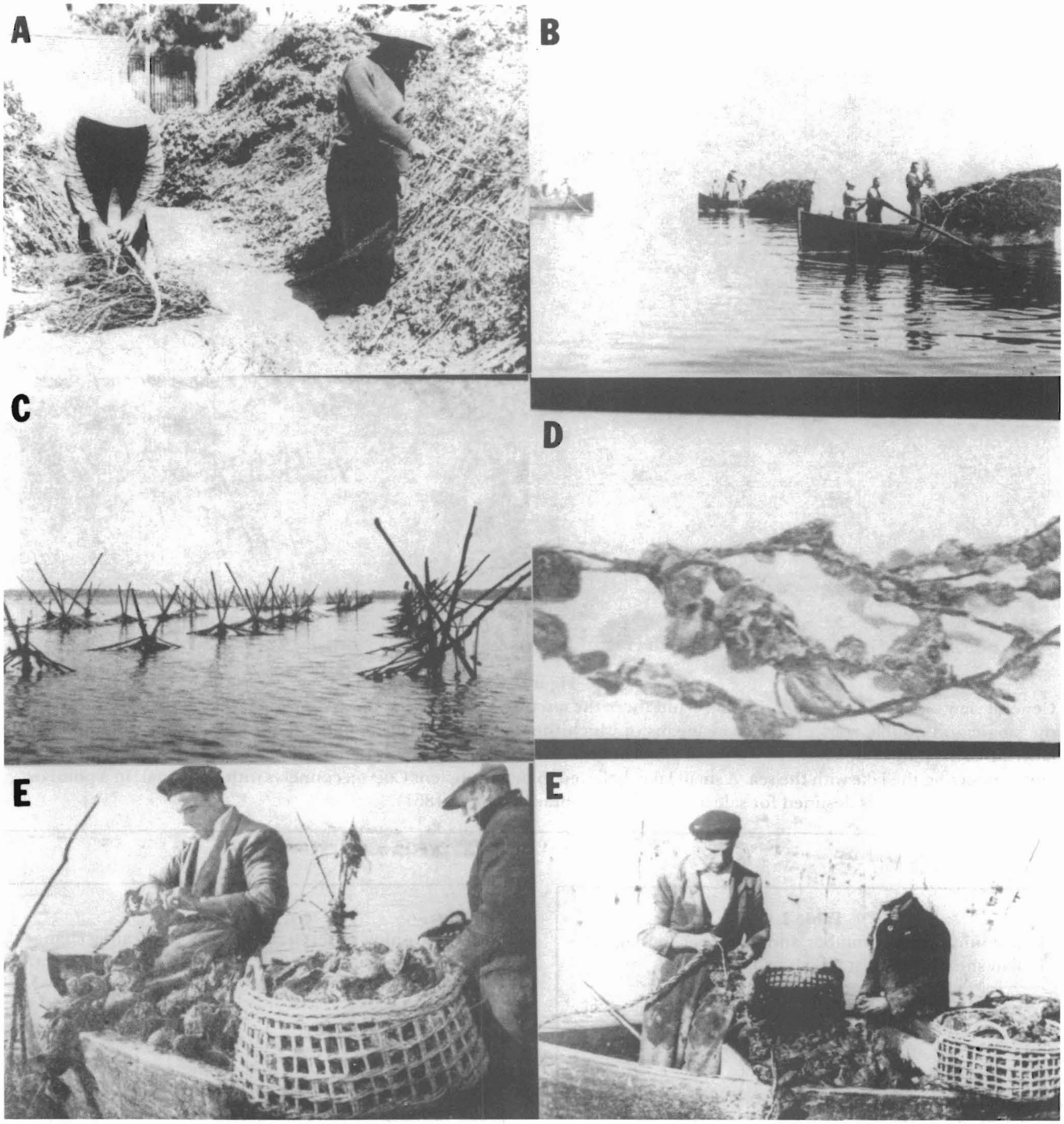

Figure 5
Traditional method for culturing oysters, *Ostrea edulis*, in southern Italy in earlier times: A) preparing bundles of branches, B) placing bundles in water (they are held down by stones), C) bundles are suspended on ropes strung between dolphins, D) oyster spat on branches, E) in both scenes, the worker at left is removing fully grown oysters from ropes, and the worker at right is breaking up clusters and putting individual oysters into baskets.

to the handle. The fishermen let out their boat anchor line perhaps 200 m, lower the rake, and then pull it along the bottom by winding in the anchor line. They retrieve the rake by hand, empty it, and then run the boat back to the previous location and repeat the operation. They often rake around an entire circle from a single anchor point. Regulations controlling the rake are: 1) The width of its mouth cannot exceed 1.5 m, 2) the mesh of the bag cannot be smaller than 20 mm, 3) the length of the bag cannot exceed 2 m, and 4) the boat must not be driven by a motor >100 hp or have a displacement of >10 t.

Open Sea Harvests

Fishermen use two principal vessel/gear types to harvest mollusks in the open sea:

1) Vessels equipped with simple hydraulic dredges, rakes, and other trawling equipment for mollusks have the following characteristics and regulatory limits. The propulsion engine can have a maximum of 150 hp for dredging; the maximum boat displacement can be no more than 10 t; and no auxiliary engines are allowed for the pumps, the power takeoff winch. or the steel cable for hauling the dredge or rake and anchor.

2) Vessels equipped with highly advanced, heavy hydraulic dredges which are capable of penetrating several centimeters into the bottom (Fig. 6, 7). This equipment has a cage frame constructed of steel bars. Its

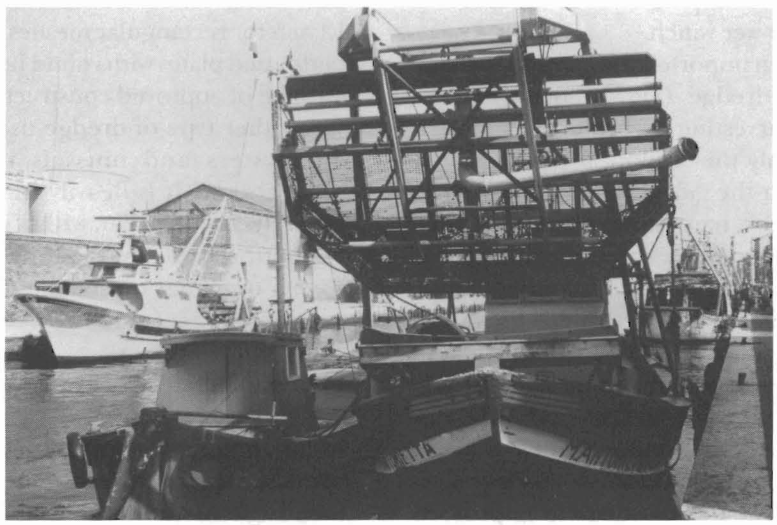

Figure 6
The front of a hydraulic dredge. Photograph by N. Mattei.

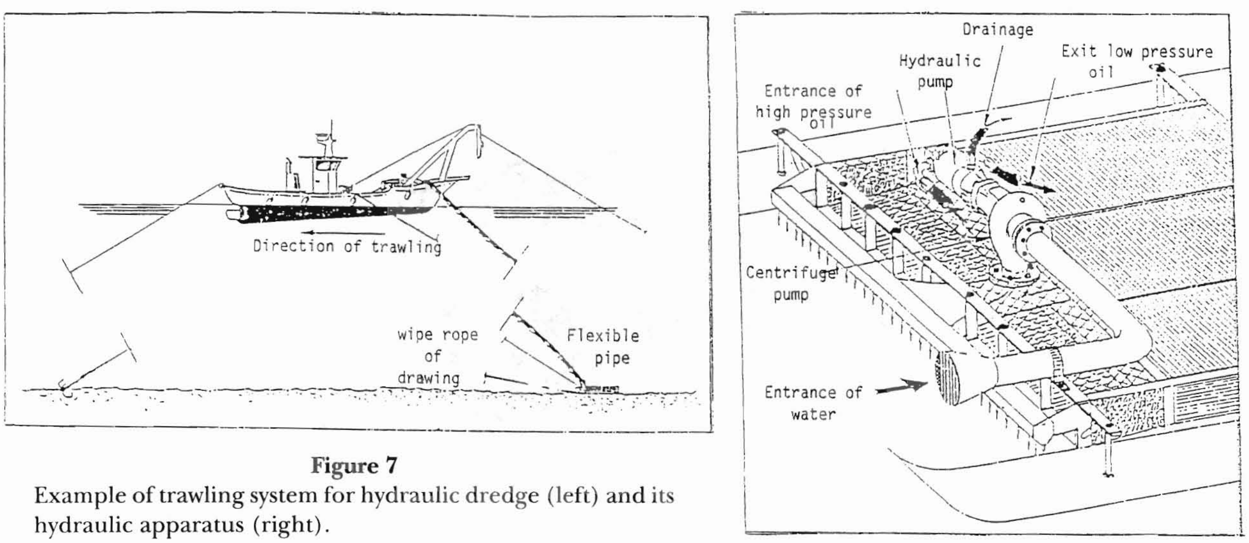

Figure 7
Example of trawling system for hydraulic dredge (left) and its hydraulic apparatus (right).

rectangular mouth is fitted with an adjustable blade and a manifold of jets running the full width of its lower leading edge. The sand and mud are fluidized by the jets and expelled through the grilled sides of the box; the mollusks are retained by the bars. Seawater is supplied, via a large hose, from a pump aboard the vessel. The general characteristics and regulatory limits on hydraulic dredges are: 1) Maximum dredge mouth width (blade length) is 3 m, 2) a rigid cage for retaining the catch must be used, 3) maximum pressure from the jets is 1.8 atmospheres, 4) dredge weight cannot exceed 600 kg, 5) the lower part of the cage must have a mesh or bar spacing which permits passage of undersized and undesired organisms, 6) the dredge must be hauled over the bottom only by warping on a set anchor, and 7) the warping must be a steel cable that is hauled in with a power winch.

In the 1960's, fishermen imported the "rapido" dredge (also termed *rampone*) dredge (Fig. 8) from France, which permitted the harvesting of hitherto untapped benthic resources, mainly the scallop, *Pecten jacobaeus*, below depths of 10 m in the Adriatic Sea. The scallop densities are too low for harvesting elsewhere. The rapido was originally designed for catching flatfish. It is light, has short teeth, a fixed mouth, and its name reflects the speed at which it can be towed. Its mouth opening consists of a rigid frame, 20–40 cm high, and its dredge bar has curved teeth and four skids to prevent the teeth from penetrating too deeply. A depression plate (diving plane) on the upper frame bar keeps the rapido on the bottom. The mesh size of its bag is variable and an apron of coarse plastic netting protects its bottom from wear. By law, the rapido used for harvesting scallops can have a mouth between 1.6 and 3.2 m wide and a bag with a minimum 50 mm mesh size. The sizes and numbers of rapidos worked simultaneously from a boat vary according to its power.

To harvest jacknife clams, *Solen* spp. and *Ensis* spp., fishermen tow hydraulic dredges with water jets on their blades. By law, the distance between the bars on the lower part of the cage must be at least 7 mm, and metal meshes must not be used. In addition, the clams must be culled by hand, the undersized animals must be returned to the sea, and sieves must not be used or kept on board.

By law, dredges for clams, *Chamelea gallina*, *Tapes aureus*, and *Callista chione*, must have cages that allow seed clams to pass through. Minimum spacing in cages must be at least 12 mm for bars, 17 mm for square metal meshes, 25 × 12 mm for rectangular meshes, and a 21 mm diameter for perforated plates with round holes. The meshes and sieves must be of approved construction and be easy to inspect.

Another type of dredge used specifically for harvesting oysters and mussels in shallow water is the "ostreghero." It is heavily framed, ranging from 110 × 30 cm to 200 × 50 cm, with a toothed bar which scrapes the bottom and a heavy cord bag with metal meshwork having openings no smaller than 50 mm.

Other Management Measures

In an attempt to control the fishing fleet and improve management of fisheries resources, the Italian government recently has tried to decrease or at least stabilize the number of boats working. In 1989, the government

Figure 8
A rapido dredge for harvesting scallops. Photograph by N. Mattei.

promulgated severe restrictions on new entries to certain fisheries. In addition, regulations for harvesting mollusks now stipulate a maximum daily catch per boat of 600 kg (1,325 pounds), 4–5 working days/week, and a limit on the number of boats working; a moratorium also exists on issuing of new licenses. Recent legislation also reduced the annual fishing period for *C. gallina* from 11 to 10 months, though it was so heavily fished in the past 10 years that it now is impossible to obtain commercial quantities.

In 1990 the establishment of molluscan sanctuaries in inshore littoral zones (from the beach to 1.5 n.mi.) was also proposed. As yet, they have not been definitively established. At the same time, installation of new propulsion engines or upgrading of old ones and rebuilding of processing plants for the mollusk fishery were excluded from federal financial assistance. Daily quotas on mollusk catches were reduced further, and the number of operating days were reduced from 5 to 4 days per week. Finally, special financial assistance was made available as an incentive to develop new aquaculture enterprises.

Condition of Molluscan Fisheries

Mussels

Mussels have the highest annual landings of any mollusk, and in 1989, Italy was second in Europe to Spain in mussel production (Fig. 9). Statistics in Figure 9, listing 100,500 t for Italy, are official government data for mussels passing through established markets, but we estimate that mussel production passing through both the officially recognized outlets and the many smaller local markets was actually about 175,000 t (5.8 million bushels) in 1992.

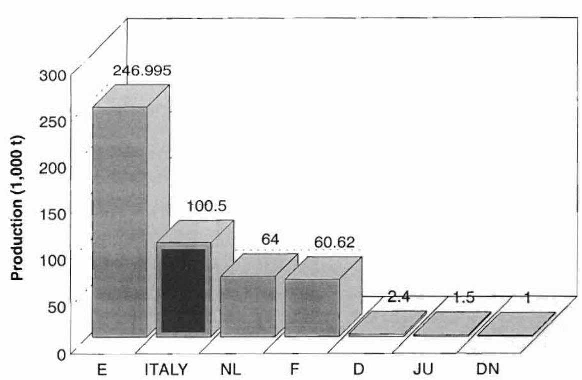

Figure 9
Comparison of mussel production among the main producers of Europe in 1989 (official quantities). E = Spain, NL = Holland, F = France, D = Germany, JU = Yugoslavia, DN = Denmark.

Culture methods are mostly traditional, but they are highly developed and give good results. Near Trieste, culturists have long-line installations for mussel culture in open sea environments. Culturists put mussels, 10–25 mm long, in mesh socks, and suspend the socks in estuarine and marine areas until the mussels have reached marketable size, 45–70 mm long, in 14–20 months (Pellizzato and Renzoni, 1989). They rework the socks as often as 4–5 times to remove the larger mussels and place them in socks with larger meshes.

A major breakthrough in the hanging culture of mussels occurred in the mid-1960's with the introduction of polypropylene mesh tubing to form the mussel cords. This material was introduced first at La Spezia and quickly spread to the northern Adriatic. This change in methodology greatly reduced the labor in preparing the cords and permitted a substantial increase in the volumes handled. Before the introduction of mesh socks, the cords were prepared by inserting small clusters of mussel seed into twisted grass rope, a slow and tedious operation.

In the shallow lagoons of Venice-Chioggia, the Po delta, Taranto, Naples, and La Spezia, culturists use two methods, known as the Venetian and the Taranto methods. They are different mainly in the configuration of the support structures of the poles or racks.

In the Venetian system (Fig. 10), the racks are permanent structures, composed of two massive end-frames which are supported by two or more dolphins of heavy pilings to which is bolted a horizontal timber. Heavy galvanized cables (12–14 mm in diameter) are stretched, with about 50 cm spacing, from the transverse member of one end-frame to the opposite member; the distance between end frames may be 100 m or more. At intermediate positions (about 5–10 m), horizontal supports composed of 15 × 15 cm timbers run perpendicularly to the cables and are supported by two or three light pilings.

In the Taranto system (Fig. 11), upright (corner) support members are constructed of considerably lighter stakes, cinched at their apex with cord or wire. The clusters of poles are arranged in a quadric pattern with spacing of 8–10 m. A heavy line is strung from corner to corner to form square cells; often diagonal runs of line are also used between corners.

In both systems, culturists hang the net socks with a short length of light cord from the cables or lines so that the tops of the socks are at or slightly above mean low water. The length of socks is a function of water depth, but a space of 0.5–1 m is left between the bottom of the socks and the sediment surface.

In the past, mussel culturists in the northern areas collected wild mussel seed from rocks and other shoreline structures, including the pilings of the culture system. In the 1980's, they tested artificial collectors made of netting and could obtain seed within their parks. The traditional method at Taranto, however, has

Figure 10
Venetian mussel culture method. Photograph by M. Pellizzato.

always used collectors made of natural fiber cords. In the past, small mussels were sometimes purchased from third parties who gathered them for sale to the culturists.

Clams

The principal species of clams harvested in Italy are *T. philippinarum* and *T. decussatus*, both produced by culture, and *C. gallina* and *C. chione*, both landed from natural stocks (Mattei and Pellizzato, 1989-E.S.A.V., 1990) (Fig. 12). Before 1983, clam production was based almost exclusively on natural stocks of *T. decussatus* and *C. gallina*. But fishermen overharvested the wild stocks and production fell. To meet the demand for clams, culturists imported *T. philippinarum* for sowing in estuarine areas beginning in 1983. This species, which grows faster than native clams (Pellizzato and Mattei, 1986, 1988; Pellizzato et al., 1989) but is morphologically similar except for its siphons, colonized Italian waters in dense numbers and restored clam production (Fig. 13).

Culturists raise *T. philippinarum* principally in lagoons and saltwater impoundments in Marano, Venice, and the River Po delta. Culture involves producing juvenile clams in hatcheries and then sowing them on the bottom. At first, the seed is held in trays to prevent predation by crabs and the gilthead bream, *Sparus aurata*, (Fig. 14). When the clams have reached 15–20 mm, culturists transfer them to firm bottoms at a density of 200–400 clams/m^2 and cover them with plastic nets to limit predation (Fig. 15, 16). In 16–18 months, the clams have grown to a commercial size of 35–40 mm.

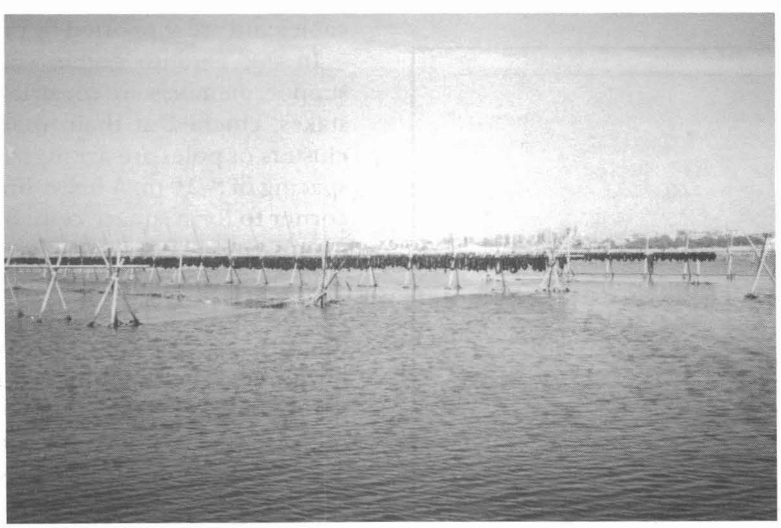

Figure 11
Taranto mussel culture method. Photograph by M. Pellizzato.

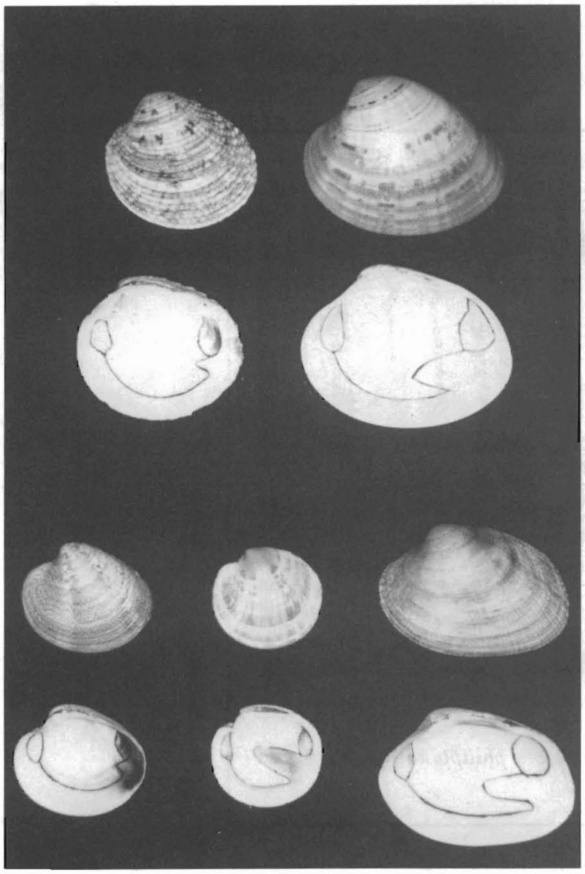

Figure 12
Five species of family Veneridae clams harvested in the Mediterranean Sea: Upper left, *Venus verrucosa*; upper right, *Callista chione*; lower left, *Chamelea gallina*; lower center, *Dosina exoleta*; and lower right, *Tapes decussatus*. Photograph by E. Rufert from collect. of Mus. Civ. St. Nat., Venezia.

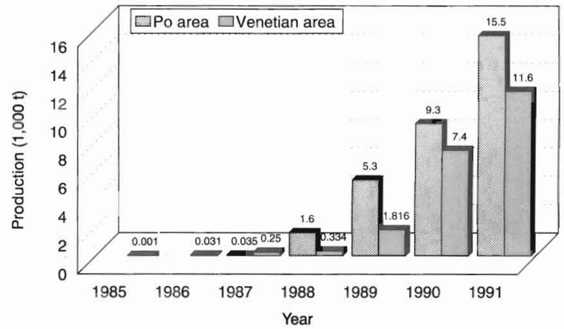

Figure 13
Production trend of the carpet clam, *Tapes philippinarum*, from 1985 to 1991, for the northeastern coast, the principal area in Italy for producing this species.

Culturists have been establishing parks or managing natural beds with great commercial success. In many areas, the species has also colonized natural bottoms and is subject to controlled harvesting as for any wild stock (E.S.A.V., 1990).

The best yields and growth rates of *T. philippinarum* have been obtained by seeding areas having a good circulation, which provides a good food supply and usually better water quality. Some areas, such as fish-farming lakes, often show less favorable conditions since they can be affected by hypoxia and extensive macroalgal blooms, with consequent weakening and even death of the clams during summer. Production of this species has risen steadily from about 15 t (about 375 bushels) in 1985 to 27,000 t live weight (about 700,000 bushels) in 1991.

Oysters

Until this century, the only oyster species cultured was *Ostrea edulis*, which is indigenous to Italy (Korringa, 1976). In the early 1900's, fishermen introduced and grew the Pacific oyster, *Crassostrea gigas*, but have since nearly abandoned oyster culturing because consumers have become cautious about eating them. *C. gigas* and *O. edulis* are cultured only in traditional areas such as the lagoons of Venice and Taranto. Culture consists simply of restocking quantities harvested from prepared and controlled environments. On a small scale, culturists also collect seed on natural and artificial substrates. They place the seed in vertically-stacked, multistory baskets that are suspended subtidally until the oysters grow to commercial size (Fig. 17).

Scallops

In the 1980's, after 30 years of intense exploitation of naturally occurring scallops, the first signs of dwindling populations were noticed. At the beginning of the 1980's, the beds of the two most important species, *Pecten jacobaeus* and *Aequipecten opercularis* (Piccinetti et al., 1986), became smaller and production fell. The situation deteriorated further in the mid 1980's to the detriment of workers who shucked and packed the scallops for market. The fishing fleet weathered the crisis slightly better with relatively inexpensive diversification to other species. As a consequence of the lack of appropriate harvest controls, the scallop resource now is on the brink of extinction. Research has begun, therefore, into the controlled production and growout of scallops.

The first attempts at culturing *P. jacobaeus* began in 1991. Culturists grow them on long-lines in the open sea (Fig. 18). The culture techniques being tried in the

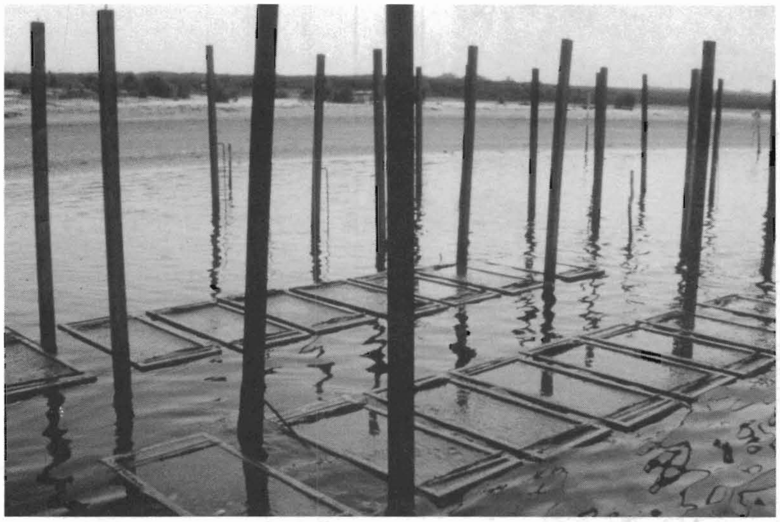

Figure 14
Growing small seed of the carpet clam, *Tapes philippinarum*, in trays. Photograph by M. Pellizzato.

Figure 15
Culturists free-seeding carpet clams, *Tapes philippinarum*, about 1 cm in size. Photograph by M. Pellizzato.

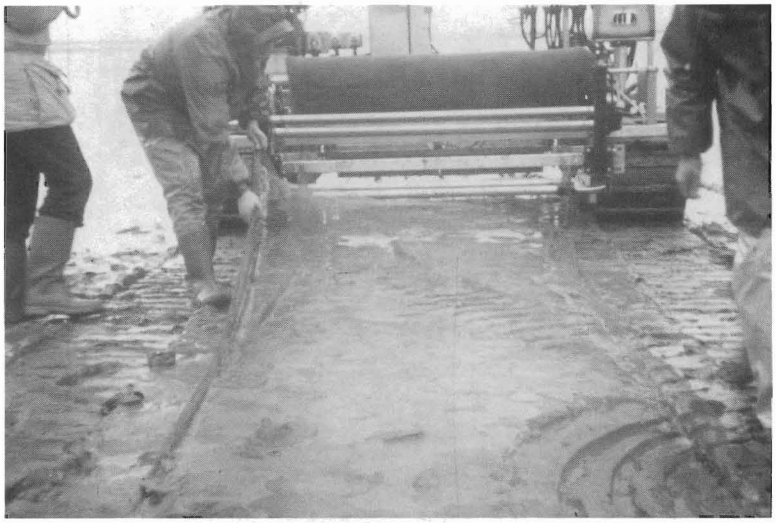

Figure 16
Culturists laying down netting mechanically to protect beds seeded with clams. Photograph by M. Pellizzato.

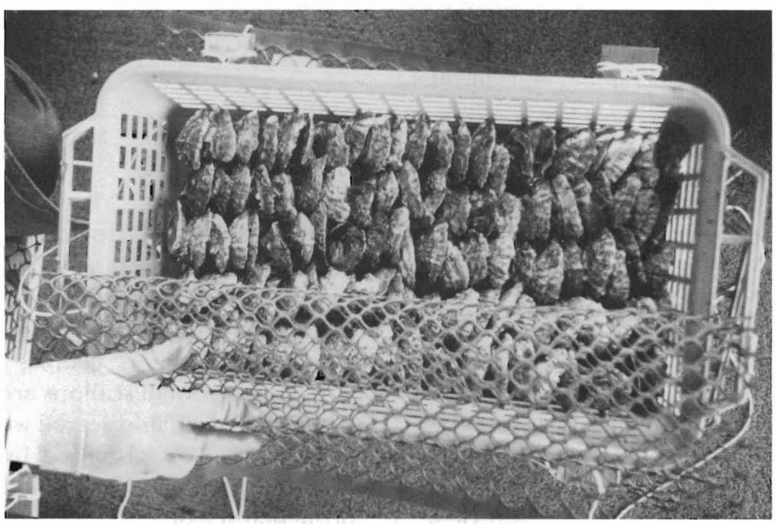

Figure 17
Growing oysters in a basket as used in a lagoon. Photograph by M. Pellizzato.

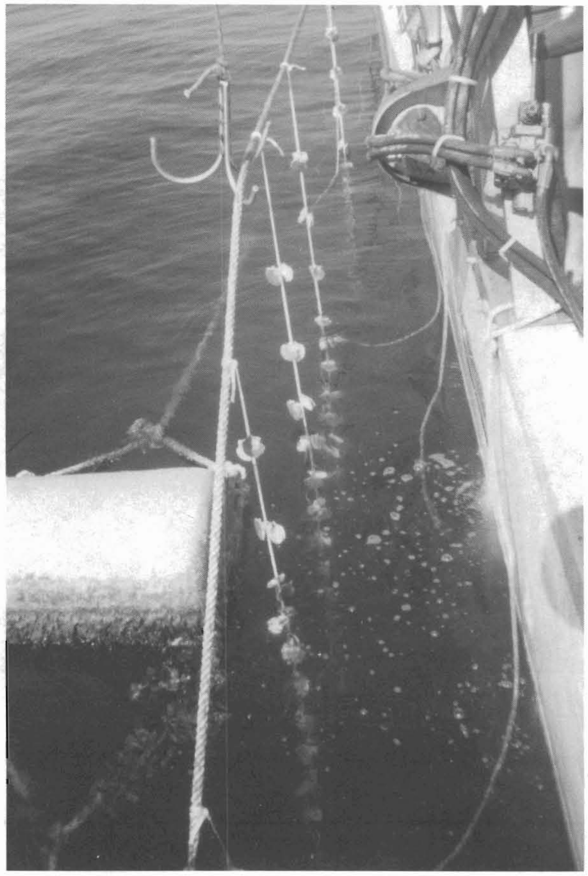

Figure 18
Italian scallop culture using the longline system. Photograph by M. Pellizzato.

northern Adriatic Sea are the same as those used in Japan and the northeast Atlantic Ocean (Mattei et al., 1992). Culturists collect wild juvenile scallops on masses of artificial filaments (Fig. 19) and suspend them by a line through a hole in a corner (ear) of their shells or by holding them in multistory lantern-net baskets. Hatcheries for clam and scallop production are also being constructed, especially in the northern Adriatic Sea. In 1991, landings (whole weight) of natural and cultured *P. jacobaeus* were about 2,500 t (estimated), and of *A. opercularis*, about 50–100 t (Fig. 20).

Snails

Fishermen, mostly in the southern Adriatic Sea, gather snails for sale by scraping rocks and diving for them using scuba gear. The snails are of the genera *Cerithium, Murex, Natica, Sphaeronassa,* and *Patella.*

Mollusk Preparation For Eating

In Italy, mollusks are eaten several ways. Mussels are steamed with vegetables and also cooked in tomato sauce. The clam, *C. gallina*, is shucked mechanically and cooked. Small scallops are eaten whole after being fried, or cooked and served with wine or a sauce. Large scallops are first prepared by cutting out the mantle and then the muscle, gonad, and visceral mass are broiled and eaten. The snails are boiled, with the large ones pulled from their shells and marinated, while the small ones are pulled from their shells and eaten directly by the diner.

The Future

Molluscan production still relies heavily on fishing natural stocks. But increasingly sophisticated equipment, inad-

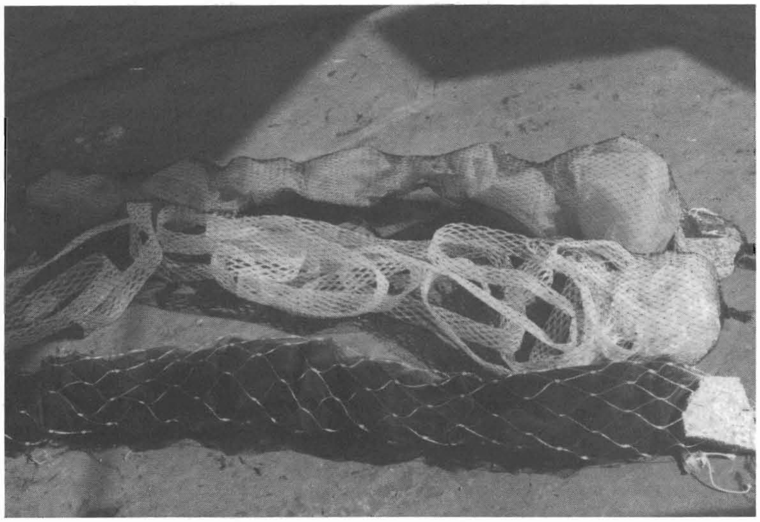

Figure 19
Examples of experimental artificial collectors of scallop spat used in the north Adriatic Sea. Photograph by N. Mattei.

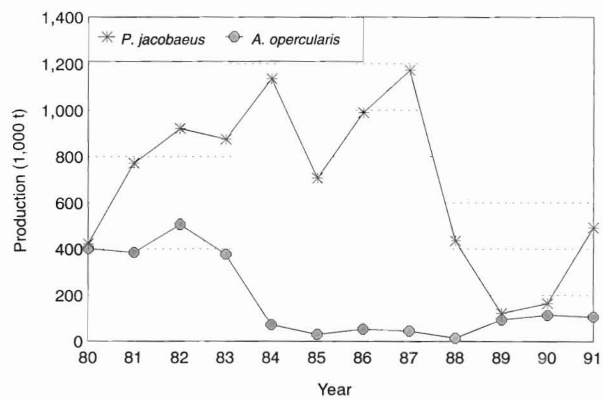

Figure 20
Scallop production trends in the principal Italian scallop port, 1980 to 1991.

equate regulations (often ignored), and a marine ecosystem damaged by pollution have depleted natural stocks. The reasons for the decline in certain resources are often multiple, and they are not always easily identified.

Aquaculture will be important in the future. The coastal lagoons are ideal for growing mollusks, but they have limits as far as production and expansion are concerned. The Adriatic Sea, with good conditions for aquaculture, also must be used. The Adriatic's elevated primary productivity would make it possible to farm mollusks in high concentrations. A secondary benefit from growing cultured mollusks is that their larvae would disperse and might reestablish or enhance populations in natural grounds.

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The History, Present Condition, and Future of the Molluscan Fisheries of Croatia

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ABSTRACT

For many years, European oysters, *Ostrea edulis*, and black mussels, *Mytilus galloprovincialis*, have been cultivated in Croatia. About 16 additional mollusks, mainly the European date mussel, *Litophaga litophaga*; Noah's arc, *Arca noae*; bearded horse mussel, *Modiolus barbatus*; and banded murex, *Phyllonotus trunculus*, have been gathered from natural beds for food and other uses. From the 16th to the 18th century, the main oyster cultivation technique was placing tree branches in the water to collect and grow spat to market size. Use of bundles of branches of the mastic tree, *Pistacea lentiscus*, continues today. After 1945, fishermen also began to cultivate mussels. They collected small mussels along the shore, intertwined them into ropes, and hung them. After 1965, fishermen switched to plastic mesh socks to hold the mussels. Molluscan farms consist of lines of ropes suspended off-bottom by buoys and anchored at their ends. Socks containing mussels or oysters hang from the ropes. Mussel production is about 3,000 t/year. About one-third are sold fresh, either exported or to local markets. The remainder are processed. Oyster production is about 2 million pieces/year. About 60 people cultivate mollusks, and about 100 families produce small quantities of mussels and oysters for local markets. During the past 20 years, the mussel, followed by the oyster, are the only mollusks landed in quantity. Targeted fishing for mollusks from natural beds is rare and is associated with finfishing, but some high-priced mollusks, such as the European date mussel and banded murex, are sought and sold in local markets. Legal, research, and the environmental issues will affect shellfisheries in the future.

Introduction

European flat oysters, *Ostrea edulis*, and black mussels, *Mytilus galloprovincialis*, have been cultivated for many years along the Croatian coast (Fig. 1). About 16 additional mollusks, mainly the European date mussel, *Litophaga litophaga*; Noah's ark, *Arca noae*; bearded horse mussel, *Modiolus barbatus*; and banded murex, *Phyllonotus trunculus*, have been gathered from natural beds for food and other uses.

Oysters and mussels were once cultivated in at least 30 sites in Croatia, but for various reasons most sites were abandoned. In the last 30 years, Limski Bay and the Bay of Mali Ston have maintained production, and a few years ago Zadar and Šibenik were brought back into production. During the past 20 years, the black mussel, followed by the oyster, are the only mollusks landed in quantity.

Habitat Description

The Adriatic Sea (surface area, 138,595 km^2; average depth, 173 m), the northernmost bay in the Mediterranean Sea, can be divided into northern, middle, and southern regions according to physical, chemical, and biological properties. The northern region is shallow, rarely exceeding 50 m, and has wide temperature fluctuations of 6°–27°C, and a salinity of 34–37‰ due to considerable inflow of water from the Po River. Biological production is higher than in other areas, primarily owing to considerable nutrients coming from the land. Its richness is portrayed through the larger quantities of relatively few species, especially pelagic communities (Revelante and Gilmartin, 1977).

The middle region extends from the 100 m isobath to the Palagruza threshold, with its greatest depth at Jabuka pit (over 200 m); it has a temperature range of 10°–25°C

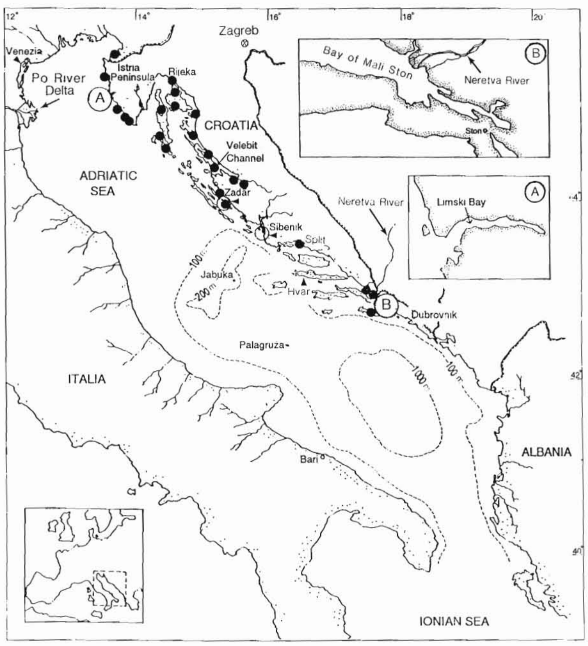

Figure 1
The Adriatic Sea and historical sites of mollusk production (closed circles) along the coast of Croatia.

and salinities of 36–38‰. The land influence here is weaker, and oscillations in ecological factors are less.

The southern region extends from the Palagruza threshold to the sea's entrance off southeastern Italy, and being directly influenced by Ionian Sea currents, is somewhat similar to the open regions of the Mediterranean Sea. It has a great depth (maximum of 1,334 m), a temperature range of 11°–23°C, and salinities of 37–39‰. The influence from the land is minimal.

The ecological characteristics are somewhat different along the Croatian coast where river mouths, closed and partly closed bays, and underwater springs strongly influence local habitats. The coast of Croatia is mainly rocky (limestone). The only areas where shellfish can grow abundantly are sand and clay bottoms near the river mouths and in a few sheltered bays (Milišić, 1991).

Most mollusk cultivation sites were in the north where ecological conditions are favorable (Buljan and Zore-Armanda, 1966), but during the last 30 years, only two, Limski Bay and the Bay of Mali Ston, maintained production, and an additional two, Zadar and Šibenik, were activated a few years ago (Fig. 1).

Limski Bay, a northern Adriatic fjord, has an average depth of 15 m and sand and clay substrates. The temperature range is 9°–26°C and salinities run 26–37‰.

Zadar, in the middle Adriatic, is sheltered, has an average depth of 12 m, a temperature range of 10°–23°C, salinities of 35–37‰, and a sandy bottom. In 1986, mussel cultivation was introduced near a culture operation of European sea bass, *Dicentrarchus labrax.* The bass culturists placed "pergolars" (plastic mesh socks) with mussels near the sea bass cages with the idea that the mussels might use phytoplankton grown on nutrients excreted by the fish.

Šibenik, also in the middle Adriatic, has an average depth of 15 m, temperatures of 8°–25°C, salinities of 18–37‰, and sand-clay bottom sediments. In 1987, mussel cultivation was introduced near the mouth of the Krka River.

The main shellfish production area in Croatia is the Bay of Mali Ston near the City of Dubrovnik in the southern Adriatic. The bay is especially productive because it is sheltered and has many underground springs. Its depth ranges from 10–26 m, temperatures from 10°–25°C, and salinities from 24–37‰. Its sediments are clay and sand.

Shellfisheries History

Prehistoric humans used shellfish for food along the eastern Adriatic coast. Prehistoric oyster and mussel shell piles were found in caves on the island of Hvar (Novak, 1955), and ancient shell piles have been found along the coast of the Istrian Peninsula, in the region of Zadar and Šibenik, and in the area of the Bay of Mali Ston (Fig. 1) (Glavina, 1976). From the times of the Roman Empire, oyster cultivation was noted in the Bay of Mali Ston, where some petrified oak branches with oyster shells were found (Skaramuca and Gjukic, 1982). The cultivation method used was the same in other regions of the Roman Empire (Heral and Deslous-Paoli, 1991). Oyster cultivation in the Bay of Mali Ston was noted in the sixteenth century (Basioli, 1982), but no information is available on methods other than the placing of oak, *Quercus pubescens* and *Q. ilex*, branches in the water and collecting them at suitable times.

More details are known only for the Bay of Mali Ston from the sixteenth century onward. The main cultivation technique until the eighteenth century was to place oak; olive, *Olea europea*; and cherry, *Prunus avium*, branches in the water and collect the marketable oysters that had set and grown on them about 3 years later (Skaramuca and Gjukić, 1982). Parallel to this, during the seventeenth century and onward, the techniques improved when oysters were grown on square wooden frames which were placed in the water during the spawning season to collect spat and retrieved after the oysters had grown (Basioli, 1982).

A "faschio," a bundle of thin 2 m-long branches about of the mastic tree, *Pistacea lentiscus*, was later invented and proved to be the best tool for collectors, and it remains in use today (Fig. 2). In the nineteenth century, faschios were removed from the bottom after a year, cut into smaller pieces, and hung on wooden "tarantine" frames (Fig. 3). After 1930, methods improved with the construction of a squared park (Fig. 4) fixed on the bottom and with the introduction of cementing small oysters onto wooden sticks. The sticks are intertwined in the rope and hung on suspended horizontal lines of the park (Basioli, 1968).

From the eighteen century until the abolition of the Republic of Dubrovnik in 1808, oyster cultivation in the bay was regulated by strict governmental rules. The Government of the Republic of Dubrovnik issued licenses to local families for oyster cultivation and levied a tax on the oysters. Notes in the Historical Archives of Dubrovnik[1] from 1641 describe the Order of the Government for obligatory checking of oysters for sale. Controls for quality and size were established in the Office for Measures and Standards. After 1711, production fell because prices declined and taxes increased[2].

In 1786 the Senate of Dubrovnik recognized the need to revive cultivation. Six families were chosen to place 1,000 oak branches each in the sea, and then 500 new ones each year. The price of oysters was 10 dinars per basket, the families and their mules were freed

[1] Notes in the Historical Archive of Dubrovnik "Diversi di Stagno," 18.02.1641.

[2] Notes in the Historical Archive of Dubrovnik "Diversi di Stagno," 24.03.1711.

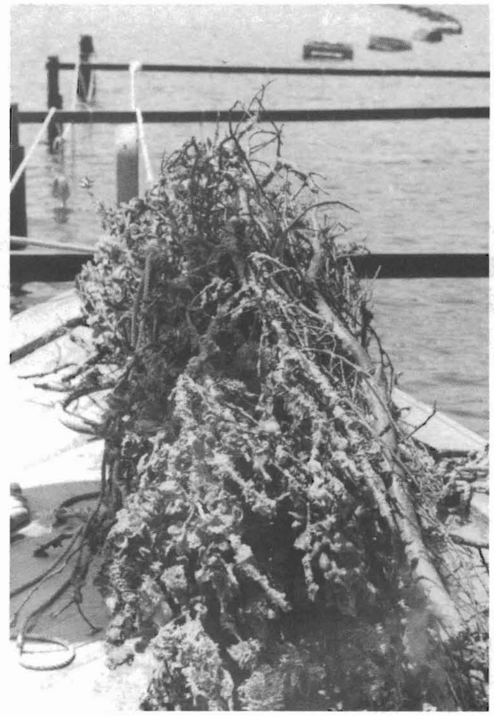

Figure 2
A "fashio" (bundle of branches) taken from the water after 7 months.

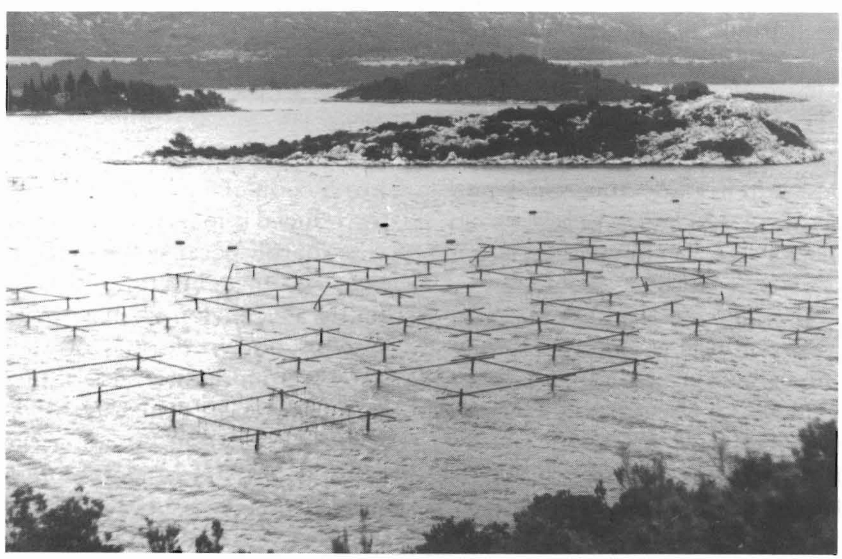

Figure 3
The oldest type of mollusk park (all wooden frames) still in use.

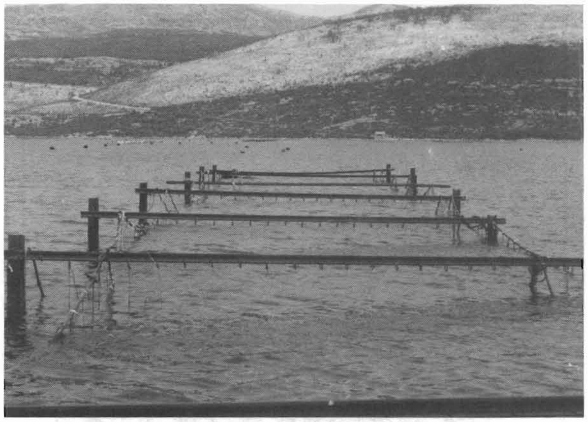

Figure 4
A wooden frame on vertical iron piles from a mollusk park set up in about 1947. It is now almost abandoned.

Figure 5
The new type of mollusk park now in use. Lines of plastic buoys are connected by ropes and anchored at each end.

from public duties, and the families were given loans[3]. In 1899 the "First Dalmatian rational cultivation of shellfish" company was founded. The company produced at least 800,000 oysters per year. Besides selling oysters locally, it exported some to Rijeka (Fiume) (Fig. 1), Berlin, and Paris. At the peak of production in 1930, the Bay of Mali Ston produced more than 1 million individual oysters (pieces). They were transported by train daily to markets in Zagreb, the capital of Croatia.

Other sites along the Adriatic coast did not maintain cultivation, but many fishermen tried to follow the example of the Bay of Mali Ston. In Limski Bay, the introduction of the tarantine method of collection and cultivation was attempted from 1888 onward (Basioli, 1968).

After 1945, some fishermen also began to cultivate mussels. They collected small mussels along the shores, intertwined clusters of them into ropes, and hung them from suspended ropes. After 1965, the fishermen switched from the ropes to plastic mesh "pergolars" to hold the mussels. The socks were also hung on horizontal ropes.

Though the consumption of oysters, and to a certain extent mussels, has a long tradition along the Croatian coast, the local population always ate a number of other mollusks. The species eaten only raw has been the oyster. The others have been served mostly in stews or grilled. A discussion of the current molluscan fisheries of Croatia can be separated into aquaculture and harvesting from natural beds.

[3] Notes in the Historical Archive of Dubrovnik "Diversi di Stagno," 27.04.1786.

Cultivated Species

The black mussel and European flat oyster are the only mollusks being cultivated. Mollusk farms, which vary in size, consist of lines of ropes suspended off-bottom by buoys and anchored at their ends. Socks containing mussels or oysters are hung from the ropes (Fig. 5).

The fouling organisms that collect on the mussels and oysters do not interfere with rearing them. In the Bay of Mali Ston, they consist of sponges, polyzoans, and tunicates; barnacles are almost absent (Igić, 1981). The off-bottom cultivation eliminates all benthic predators. The main predator of both species is the sea bream, *Sparus aurata*.

Black Mussel

In the past 20 years, this mussel has had the highest production of any mollusk in Croatia. After 1945 it was introduced into farms for trials, and mussel production rose sharply because the market for it was strong and it was easy to cultivate. Mussels are cultivated in four farms, i.e., in Limski Bay, in the Zadar and Šibenik regions, and in the Bay of Mali Ston, the latter farm produces more than 50% of the total (Fig. 6, 7).

Large ropes, primarily used for collecting mussel spat, are placed in the water where the larvae concentrate. In the Bay of Mali Ston, larvae set near the surface. If this seed supply is insufficient, workers collect additional quantities from natural beds along the shores, and a few times in the past 20 years, a limited quantity had to be imported from Italy.

After about 6 months, workers remove the small mussels from the ropes, put them in "pergolars" about 4 m

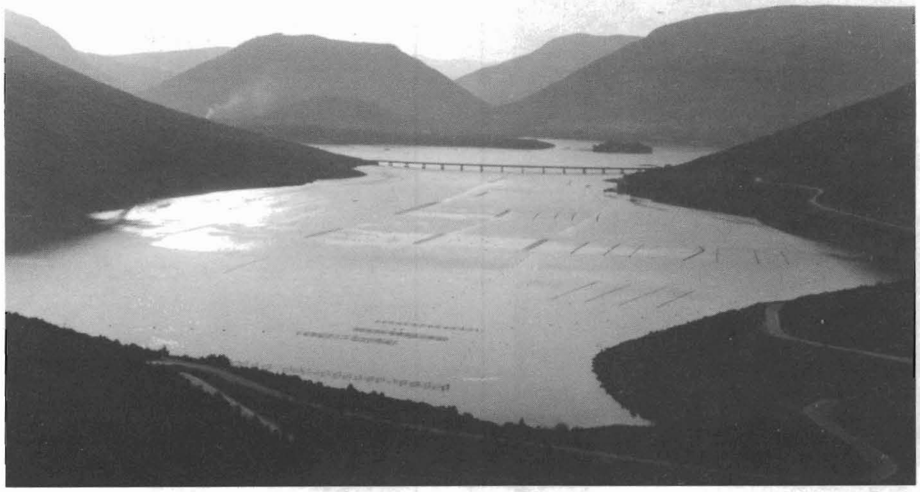

Figure 6
North-south view of the most productive subarea of the Bay of Mali Ston (Bistrina). It produces about 600 t of mussels (20,000 bushels)/year.

long, and hang them on the lines (Fig. 8, 9). After 6–8 months, the mussel socks are harvested. The large mussels are delivered to markets, and the small ones are put back in the socks for further growth. The entire growth period from spat to market size is about 18–20 months. Mussels have their highest quality in the summer.

Mussel production in Croatia was about 3,000 metric tons (t) (100,000 bushels)/year in 1990. About one-third of the mussels are sold fresh, either exported or to local markets where they sell for US$1/kg. The remainder are processed, principally by steaming them in funnels, separating the meats from the shells, and deep freezing the meat. Frozen mussel meat is packed in quantities of 0.25, 0.5, and 1 kg. Mussels are exported mainly to Italy. The Italian buyers visit the Croatian farms and purchase the mussels directly from them.

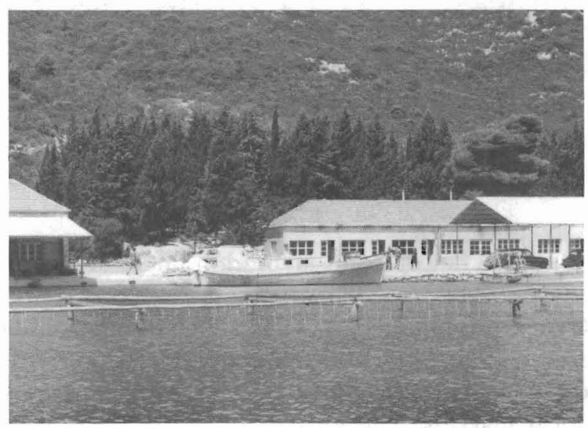

Figure 7
A view of the "Dalmacijabilje" Company in the Bay of Mali Ston.

European Flat Oyster

The oyster is now grown only in Limski Bay and the Bay of Mali Ston. The main type of spat collector is still the "fashio," as in the past, but plastic plates of various sizes (small, 20×20 cm; large, 50×50 cm), "Chinese hats," and some other types have been tested, and their use is slowly growing (Fig. 10, 11, 12). Workers place collectors in traditionally known spat beds and, after about 6 months, remove them from the water. They cement the small oysters onto pieces of wood or thin ropes. These are then intertwined into thick ropes about 4 m long. The thick ropes are then suspended from the ropes in the farms and left there until the oysters attain market size. Workers put any oysters that are too small for market in baskets and suspend them again in the farms for further growth.

The entire growth period from spat to market size is about 18–20 months as with mussels. Oysters are of highest quality during the winter. Traditionally, St. Joseph Day (19 March) is known as the day for judging the annual harvest. In the Bay of Mali Ston (Town of

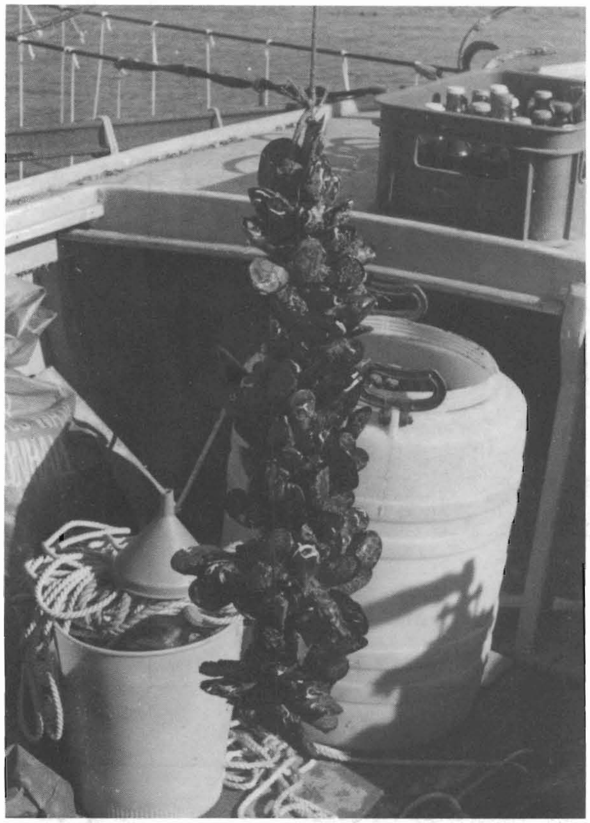

Figure 8
Experimental "pergolar" with 12-month-old mussels from 6 m depth.

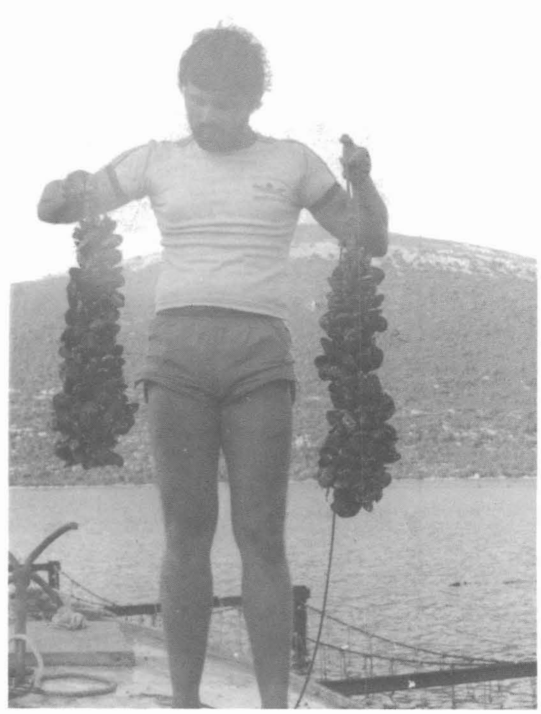

Figure 9
Researcher from the Biological Institute, Dubrovnik, holding experimental "pergolars" with 8-month-old mussels from 6 and 8 m depth.

Ston), it is a day of local celebration, including church processions, barbecues, and sales of souvenirs.

Oyster production in Croatia was about 2 million pieces in 1990, of which the Bay of Mali Ston produces about 60%. The entire production is sold fresh, mostly at local markets, where oysters sell for $0.10 apiece. Somewhat less than 30% of the production is exported to Italy.

Companies and Workers

In Croatia, only three companies[4] are involved in mollusk production. They are Marimirna in Limski Bay, Cenmar in Zadar, and Dalmacijabilje in Dubrovnik (Bay of Mali Ston). Though the companies produce fish also, an estimated 60 people work in mollusk cultivation. In addition, about 100 families produce small quantities of mussels and oysters for local markets.

[4] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Sanitary Control

The government has regulations for the control of water quality and meat quality, which are checked by veterinary authorities. With regard to new investments in aquaculture projects, site selection and the capability of the investor to cultivate mollusks have to be checked by authorized institutions. A license is issued after government approval of the necessary documents.

Harvesting Natural Mollusks

Targeted fishing for mollusks from natural beds has been rare and is associated with finfishing, such as trawl-netting, gill-netting, and drag-netting. But some precious or high-priced mollusks, such as the European date mussel, or traditionally fished species, such as the banded murex, have been sought by fishermen and sold occasionally in local markets. The other mollusks have been caught mainly for home use or for bait by sportfishermen. No statistics on numbers of fishermen or landings are available for these species. The following are mollusks, other than European oysters

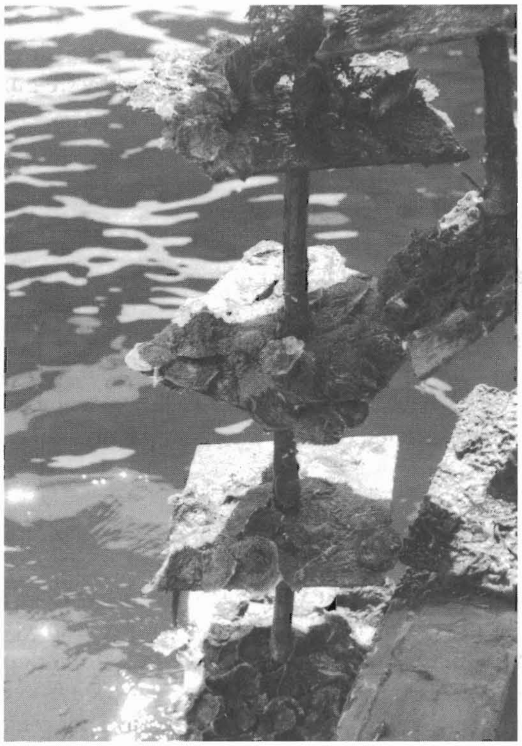

Figure 10
Plastic plates, a new type of oyster spat collector. The oysters are about 3 cm in diameter and 8 months old.

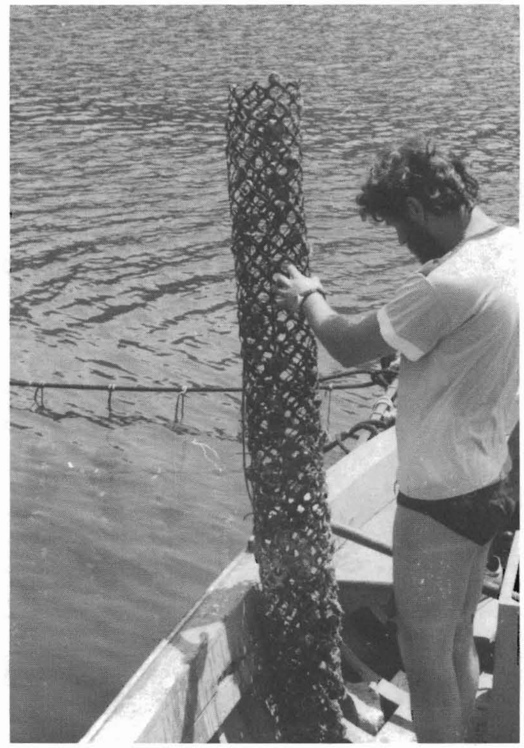

Figure 11
Researcher from Biological Institute, Dubrovnik, examines a new type of oyster spat collector.

and black mussels, with distributions, collection methods, and uses.

European Date Mussel

Called "prstac" in Croatia, this species is found along all rocky coasts, preferring dolomites. The better known beds are on the western coast of the Istria Peninsula, the Velebit channel, the Split area, and the Bay of Mali Ston. Date mussels bore into rocks and inhabit the perforations. They are harvested year-round.[5] Fishermen dive for them without tanks, use a chisel and hammer to smash the surface of the stones, and then pick out the mussels with forceps. In the past, solitary stones and parts of stones used to be taken ashore and carefully smashed to get the mussels, but now taking the stones out of water is forbidden.

The species' meat is excellent and is a specialty in restaurants. It is eaten steamed, with the addition of some spices. These mussels are rarely found in local markets, as they are mainly sold directly to restaurants. They are an excellent bait for the sea bream and other fishes of the same family.

[5] In 1995 (after this article was written) the Croatian government banned further harvesting of the European date mussel.

Noah's Ark

Called "kunjka" in Croatia, this species is distributed along all rocky coasts. The best known beds are in the Istria Peninsula, the Zadar area, and the Bay of Mali Ston.

Noah's ark is harvested year-round by boats using modified rakes (kunjkara), or by diving and hand collection. The meat is tasty and eaten raw, steamed, or grilled without spices or other additions. It is occasionally found in local markets, and sport fishermen use it for bait.

Bearded Horse Mussel

Called "runjava dagnja" in Croatia, this species is rather scarce, but is found along rocky shores, mainly at depths below 2 m. It is most abundant in the Bay of Mali Ston, Bay of Kaštela (Split region), and Murter Island (Šibenik region).

Figure 12
Detail of the new type of oyster spat collector. Diameter of the year-old oysters in front is about 5 cm.

The bearded mussel is collected year-round with modified rakes or by diving and hand collection. The meat is served raw or steamed, but only rarely sold in local markets.

Noble Pen Shell

Called "periska" in Croatia, the noble pen shell, *Pinna nobilis,* is common in the coastal zone of the Adriatic Sea on sandy bottoms in 2–20 m depths. This is the largest shellfish of the Adriatic Sea, and some reach 1.2 m in length. It was once collected year-round by diving or by using special pincers called "losnar."

The meat can be prepared by steaming, but the species was caught mainly for its decorative shell. However, the noble pen shell has become rare, and since 1976 it has been a protected species; it is unlawful to catch and sell them.

Great Mediterranean Scallop

Called "jakopska kapica" in Croatia, the great Mediterranean scallop, *Pecten jacobeus,* is common in the coastal zone of Adriatic Sea on sandy bottoms at 8–30 m depths. It is common in the Zadar area and the Hvar channel and is collected year-round by diving or using trawl nets. The meat is edible and is prepared by steaming. It is caught for its meat and decorative shells.

European Thorny Oyster

Called "kopito" in Croatia, the European thorny oyster, *Spondylus gaederopus,* is uncommon, but occurs along all rocky shores to a depth of 30 m, usually attached to stones covered with algae. It is collected year-round by diving or using a special rake, the "kopitar." The meat is edible and is served raw with a few drops of lemon. It has no market value.

Tuberculate Cockle

The tuberculate cockle, *Acanthocardia tuberculata,* called "kapica prugasta" by Croatians, is found along the entire Adriatic shore on sandy bottoms at 2–15 m depths. It is most common near river mouths near the west coast of the Istria Peninsula and in the Zadar and Split regions. It is collected year-round by diving or using rakes or dredges. The meat is edible, but has no market value. The cockle is used more for bait and for its decorative shells.

Poorly Ribbed Cockle

Called "obicni vaganj" in Croatia, the poorly ribbed cockle, *Acanthocardia paucicostatum,* is common in the Adriatic Sea and found on sand and clay bottoms at depths of between 5–200 m. Randomly taken in trawl catches, the meat is edible but rarely available in local markets.

Olive Green Cockle

Called "kapica srčanka" in Croatia, the olive green cockle, *Cerastoderma glaucum,* is common in the Adriatic Sea, occurring on sand-clay bottoms mostly between 4 and 10 m. It is taken by dredging, raking, and diving. The meat is edible, often served raw with lemon or steamed, and is occasionally sold in local markets. It is also used as bait for the sea bream.

Grooved Razor Shell

Called "cjevasti šljanak" in Croatia, the grooved razor shell, *Solen marginatus,* occurs close to shore near river mouths, on sandy and sand-clay bottoms of 0.3–3 m depths. It is taken year-round by a special tool made of wire or by modified spoons for collection of sea sand. Usage is the same as for the European date mussel, but it is scarce because its spatial distribution is narrow.

Warty Venus

Called "prnjavica" in Croatia, the warty venus, *Venus verucosa*, is common in the Adriatic Sea on sand and gravel bottoms at 1–15 m depths. It is collected mostly during the warm months by rake or by hand. It is rarely sold in local markets, though the meat is edible. It is prepared by steaming.

Grooved Carpet Shell

Called "kučica" in Croatia, the grooved carpet shell, *Ruditapes decussatus*, is common in the Adriatic Sea, mostly near river mouths. It occurs on clay-sand bottoms close to shore in shallow areas. It is gathered by hand at low tide mostly during the winter. The grooved carpet shell has excellent meat, is considered a specialty, and is usually eaten at home. Occasionally it is sold in local markets, and sport fishermen use it for bait.

Rayed Mediterranean Limpet

Called "plavi priljepak" by Croatians, the rayed Mediterranean limpet, *Patella caerulea*, a common Adriatic snail, is found in tidal zones on rocky shores. It is collected year-round, but is of best quality during the winter. Fishermen harvest it with knives at low tide. The meat is edible but rather hard when eaten raw. It is steamed and served with some spices as an appetizer, mostly at home. It is rarely sold in markets.

Turbinate Monodont

Called "ugrc" in Croatia, the turbinate monodont, *Monodonta turbinata*, another common Adriatic snail, is found in intertidal zones on rocky shores. It is collected during low tide by hand, mostly at night. Turbinate monodonts are cooked in saltwater and must be removed when the water boils. The meat is especially tasty and is taken from the shell with a needle. Finfishermen eat it while waiting for a catch with longlines. It is rarely sold in markets.

Common Pelicanfoot

Called "pelikanovo stopalce" by Croatians, the common pelicanfoot, *Apoorhais pespelicani*, is found on sandy and clay Adriatic bottoms at depths of 10–55 m. It is collected by diving, by hand, or in trawl net catches. The meat is edible, but it is collected mainly for its decorative shell; it is rare in local markets.

Helmet Ton

Called "puž bačvuš" in Croatia, the helmet ton, *Tonna galea*, is the largest Adriatic Sea snail. It is common in the middle and southern parts, mostly among the islands in the middle of the Adriatic coast, on sand and sand-clay bottoms, at depths of 20–150 m. This species was once taken year-round, mostly at night in trawl net catches. It is protected by the government.

The meat is edible but rarely so used. It is usually collected for its decorative shell. In the past, the shells were used as containers and tools for decanting olive oil.

Banded Murex

Called "kvrgavi volak" by Croatians, the banded murex, *Murex trunculus*, a common Adriatic Sea snail, is found on hard bottoms at depths of 2–50 m. It is most common in the Zadar and Split regions on bottoms fouled by algae and near concentrations of organic matter.

These snails are scavengers, and fishermen gather them using a trap baited with meat or collect them from gill nets year-round, but mostly in summer. The meat is edible and served steamed, mainly at home. They are rarely sold in local fish markets, but they make good bait for sport fishing.

Zoned Miter

Called by its scientific name *Mitra zonata* in Croatia, this snail is rare and occurs on clay and coral bottoms at depths of 20–100 m. It is caught in trawl nets, but rarely. This is the most precious and valuable snail of the Adriatic Sea and is highly appreciated by malacologists, but its collection and sale is forbidden by the government.

The Future

Important factors that will affect Croatian shellfisheries include 1) legal issues, 2) research, and 3) environmental issues. First are new regulations that should favor aquaculture projects. Governmental steps toward new fishery laws include one relating to aquaculture, and particular articles will encompass shellfish cultivation. There are two problems to be solved: 1) Rules for site selection and licenses and 2) monitoring the environment and production. In this regard, one of the future obstacles that could arise is strict regulation of the European Community, which is the potential export market, and the inability of Croatia to follow these rules because of the lack of specialized experts and sophisticated equipment. Croatia will need to seek help from more developed countries to establish acceptable monitoring.

Second are needs to expand research to develop aquaculture, including mollusk cultivation. Research is needed for new species to be cultured. Current research is aimed at developing new culture methods, and some, especially for testing for presence of oyster larvae, are already being given to fishermen for use. A principal goal is to reduce the labor needed to collect seed oysters and cement them onto wood and ropes. Research is aimed at having collectors that would remain in the water until the oysters attain commercial size. A new species to be introduced is the great Mediterranean scallop. To expand mollusk culture methods, an exchange of knowledge with experts from other shellfish regions will be needed.

Third is maintaining the present quality of the marine habitat and preventing future pollution. Designated areas for future investments in aquaculture projects need protection. This is closely followed by the necessity for coastal zone planning, which should separate incompatible human activities, i.e., industrial vs. aquaculture development. This should be reflected by legislation, as well as efficient governmental services that will enable an increase in aquaculture projects.

Taking into account the present increased interest for new investments in aquaculture, total mollusk production, mainly that of mussels, could increase to about 20,000 t in the next 10 years. Prerequisites are new management, research, effective pollution control, and expanded European markets.

Acknowledgments

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A Review of the Molluscan Fisheries of Turkey

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ABSTRACT

Large quantities of mollusks grow in Turkish waters, but Turks usually eat only the black mussel, *Mytilus galloprovincialis*. Fishermen have gathered the mussel for many years. Other species never were gathered until about 1970 when markets for them were found in Europe and Japan. Since then, fishermen have gathered at least eight species. The striped venus, *Venus gallina*, is gathered (30,000 t/year) by 1,000 boats and 2,500 fishermen using dry dredges and hydraulic dredges. When a market for the sea snail, *Rapana venosa*, developed in Japan, a fishery for them was established in the Black Sea. Fishermen harvest 550 t of meats/year by dredging or diving. The flat oyster, *Ostrea edulis*, is harvested by diving or dredging (1,500 t/year). The short-necked clam, *Tapes decussatus*, is harvested with shovels, rakes, or by diving (250 t/year). The black mussel occurs along every coast, and about 200 fishermen harvest it by diving or dredging (1,000 t/year). About 100–150 fishermen in Ayvalik Bay harvest 200–600 t/year of horse mussels, *Modiolus barbatus*. The future of the molluscan fisheries will depend on the strength of foreign demand, because the local demand is negligible. Some farmers are becoming interested in culturing the oyster, short-necked clam, and black mussel.

Introduction

Turkey is surrounded by water on three sides: the Black Sea on the north, the Aegean Sea on the west, and the Mediterranean Sea on the south (Fig. 1). Its coastline is about 8,000 km long. Large quantities of mollusks grow in Turkish waters, but the people of Turkey eat only the black mussel, *Mytilus galloprovincialis*. Fishermen have gathered the mussel for many years for sale to people in shore towns and in large cities, such as Istanbul and Izmir, but only about 1% of the population eats them. Other species were not gathered until about 1970 when markets were found for some of them in Europe and Japan. Since then Turkish fishermen have gathered at least eight species; all except the black mussel are exported. Estimates of mollusk production are difficult to make because statistics are incomplete, showing only that annual production is variable.

Species, Methods, and Quantities Produced

The mollusks produced in Turkey in order of their importance (Fig. 2) are: 1) striped venus, *Venus gallina*; 2) sea snail, *Rapana venosa*; 3) oyster, *Ostrea edulis*; 4) short-necked clam, *Tapes decussatus*; 5) black mussel, *Mytilus galloprovincialis*; 6) horse mussel, *Modiolus barbatus*; 7) kidonya, *Venus verrucosa*; and 8) *Arca* sp.

Striped Venus

This clam is the smallest shellfish that has commercial importance in Turkey. Its shell is cloudy white outside and bright white inside. Weights and sizes of the clams are listed in Table 1.

The striped venus occurs abundantly in sand bottoms in the north Aegean Sea, the Sea of Marmara, and the Black Sea near Istanbul, in depths up to 15 m (Fig. 1). Commercial fishing for them began in 1985. The number of boats and fishermen gathering them in 1990 was 779 and 2,153, respectively, in the Sea of Marmara and Aegean Sea (Table 2).

Besides those, about 200 boats and 350 fishermen gathered them in the Black Sea. Thus, the total number of boats is about 1,000; the number of fishermen is about 2,500. The boats are from 5 to 10 m long, and fishermen use two collecting methods. The principal one is towing a dredge which measures 80 cm wide and 20 cm high (Fig. 3). The second method is a hydraulic dredge, which consists of a jet head, a knife blade, and a cage (Fig. 4). The bottom is jetted in front of a knife blade and the largest striped venus collect in the cage. The dredge is retrieved and emptied on deck. In 1990, there were four boats using hydraulic dredges, two at Istanbul and two at Canakkale on the Dardenelle (Fig. 5).

Some of the striped venus are canned in factories. These, as well as live striped venus, are exported to European countries. Production of the striped venus was estimated at 4,169 metric tons (t) in 1988, 12,700 t in 1990, and 30,000 t in 1991.

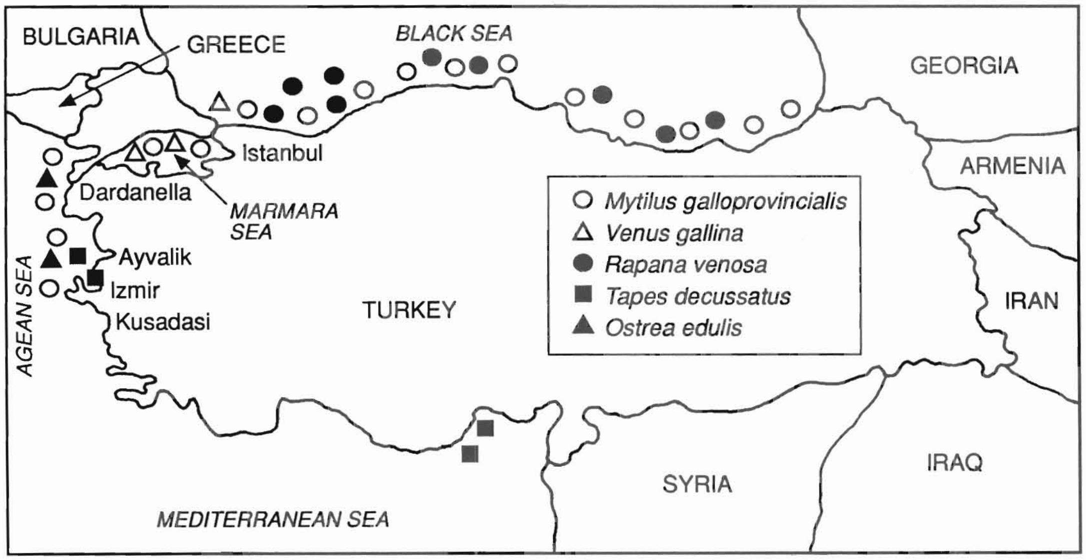

Figure 1
Main areas of molluscan shellfish production along the coasts of Turkey.

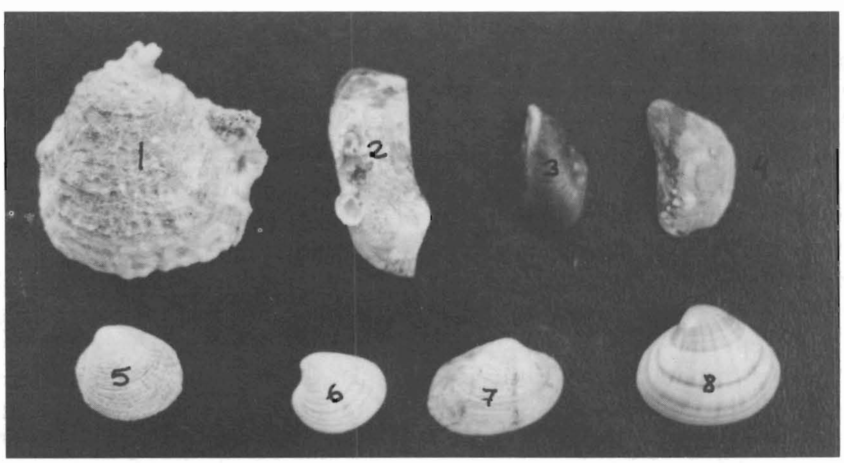

Figure 2
Principal molluscan shellfishes gathered in waters of Turkey: 1) *Ostrea edulis*, 2) *Arca* sp., 3) *Mytilus galloprovincialis*, 4) *Modiolus barbatus*, 5) *Venus verrucosa*, 6) *Venus gallina*, 7) *Tapes decussatus*, and 8) *Tapes aureus*.

Sea Snail

Sizes and weights of the sea snail are given in Table 3. Until recent years, the sea snail (Fig. 6) was not an important commercial species, but when a market for it developed in Japan, a fishery was founded in the Black Sea and it has now become important. The snails occur at depths up to 100 m, but most are gathered from

Table 1
Morphological values (number = 134) for striped venus (Alpbaz et al. 1990).

Category	x + Sx	%V	Min.	Max.
Total weight (g)	9.76 ± 0.07	27.69	4.0	15.15
Shell weight (g)	6.70 ± 0.06	26.12	3.13	11.28
Meat weight (g)	2.82 ± 0.05	32.17	0.87	5.04
Body length (mm)	27.6 ± 0.01	8.70	21.00	33.00
Body width (mm)	29.1 ± 0.02	11.00	22.00	36.00
Body thickness (mm)	16.5 ± 0.01	10.30	12.00	23.00

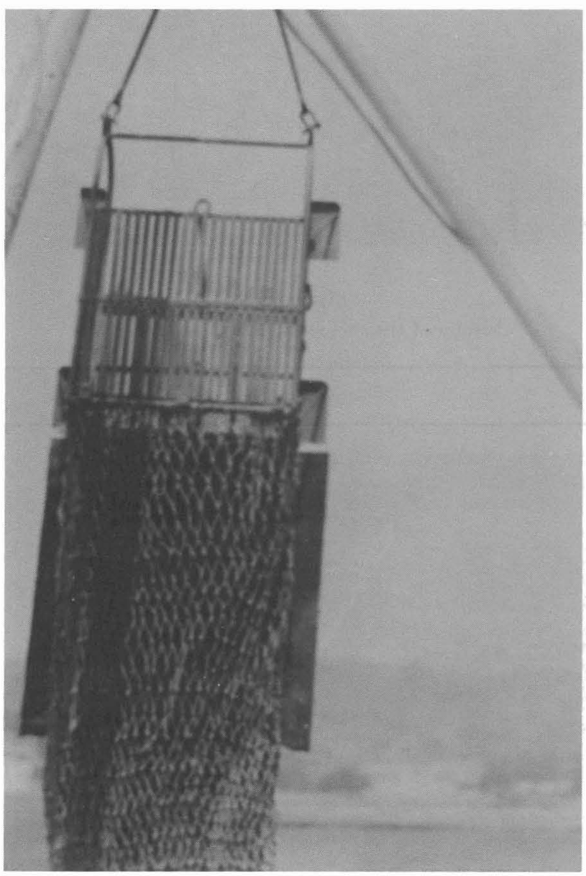

Figure 3
A dredge used for gathering *Venus gallina.*

Table 2
Number of fishermen and boats fishing for striped venus in 1990.

Location	No. of boats	No. of fishermen
Istanbul	86	264
Tekirtag	71	307
Bursa	302	892
Balikesir	120	140
Canakkale	200	550
Total	779	2,153

Figure 4
A dredge used for gathering *Venus gallina.* The dredge works with water pressure.

Figure 5
Boats dredging for *Venus gallina.*

depths of 30–40 m. The most common gear is the dredge, but some fishermen gather them by diving.

Landing sea snails below a length of 45 mm is prohibited, to conserve the stocks. Fishermen, who use dredges, gather undersize as well as legal size snails and return the small ones.

The meats are first prepared in factories and then exported. In 1987 the quantity of meats exported was 500–600 t.

Oyster

Ostrea edulis is the only oyster species in Turkish waters. No research has been done on it, except for the meristic measurements of oysters from Izmir Bay (Table 4).

Fishermen use two methods for gathering oysters. One is by divers, who pick them up by hand. Each gathers from 30 to 100 kg per day, depending on abundance of the oysters. The divers use air supplied from a surface boat. The principal oystering area is Izmir Bay, where divers from 10–15 boats gather them (Fig. 7).

Oysters are also gathered using dredges in Izmir Bay and Dardenelle, although this method is unlawful. Each fisherman can dredge up 100–200 kg per day.

Oysters from Izmir Bay are superior to those in Dardenelle, because their shells remain more tightly closed and retain liquid better. Dardenelle oysters that lose their shell liquor are sometimes dead before they reach markets mainly in Italy and Spain. In 1991, production was about 1,500 t.

Short-necked Clam

This clam has the highest value per unit volume of the shellfish landed. The reason for the high price is the difficulty in meeting the demand for them, because the fishing season is from October to April when the water is rough and cold. Fishing is forbidden in summer because that is their spawning season.

The short-necked clam is gathered principally in Izmir Bay (Fig. 1). Fishing for them began in 1970, and three methods are used. The most common is using a shovel

Table 3
Average morphological values of the sea snail by collection area (Duzgunes et al., 1988).

	Collection area			
Category	Muddy bottom	Sandy bottom	Grassy bottom	Grassy and sandy bottom
Body length (mm)	56.0	53.0	66.0	65.0
Weight (g)	35.0	30.0	70.0	70.0
Shell weight (g)	24.4	22.6	50.0	53.3
Meat weight (g)	8.8	6.9	17.3	17.6

Table 4
Meristic values (110 oysters) of *Ostrea edulis* (Alpbaz et al. 1990).

Category	X ± Sx	%V	Min.	Max.
Body weight (g)	148 ± 5.0	38	46	361
Meat weight (g)	17 ± 0.6	38	2.2	34
Percent meat	12 ± 0.1			
Shell length (mm)	90 ± 1.2	15	57	160
Shell width (mm)	72 ± 0.9	14	53	97
Shell thickness (mm)	37 ± 0.7	20	21	60

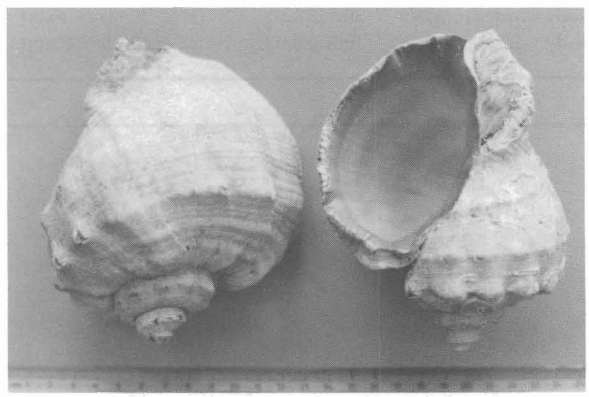

Figure 6
Shells of the sea snail, *Rapana venosa.*

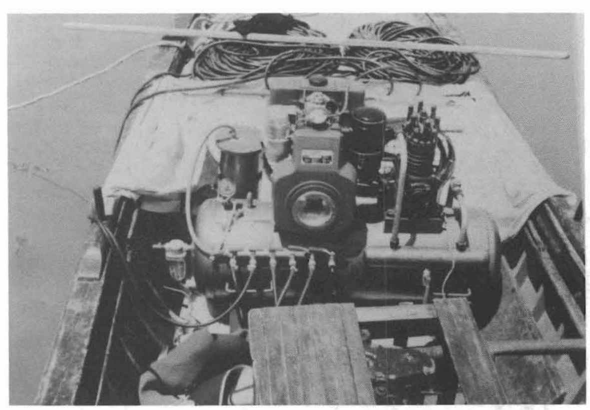

Figure 7
Boat equipped with an air pump for gathering of oysters by diving.

in wading depths. The clams are emptied into a wire screen box which retains the clams but not the sand (Fig. 8). They are then put in a sorting box ashore to separate large from small clams (Fig. 9). The small clams are the ones that are sold.

Another method is to use rakes from boats 4–4.5 m long. The handle of the metal rake, locally termed a "sara," is 3–4 m long.

The third method is by divers gathering the clams by hand. The collection sites are in 1 m of water where the bottom is muddy. Such sites are difficult to find, so individual fishermen keep the locations of the sites a secret.

The quantities landed from 1976 to 1980 were 201, 149, 254, 618, and 416 t, respectively. Some pollution problems in Izmir Bay have kept production lower than it could have been.

Figure 8
Fishermen gathering the short-necked clam using shovels.

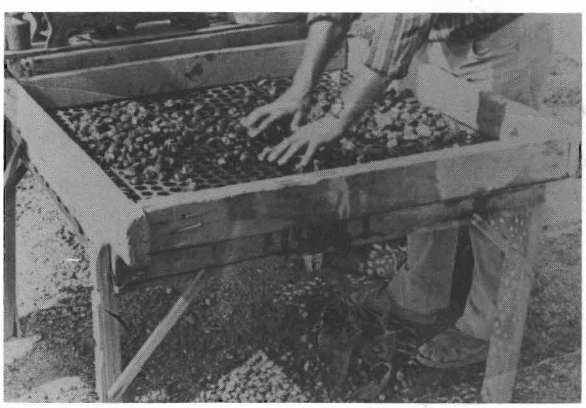

Figure 9
Selecting small short-necked clams by using a sieve.

The landed value of the short-necked clam is US$5.00/kg. Its exported value is about US$9.00/kg.

Tapes aureus also occurs in Turkish waters, but because its flesh is not highly desired it is not gathered commercially. Some farmers, whose numbers were as high as 200–300, used to come to the shores in the cooler time of the year when things were slow on their farms and gather *Tapes aureus* from October to May. Each collected from 10 to 80 kg of *Tapes* per day. They did need to obtain permission from authorities to collect them. They used to sell them for US$2–3/kg. The export market paid US$5–6/kg for them. Production has been declining, because pollution is increasing in Izmir Bay. We believe that there is a need to do research on pollution problems and their effects on production of shellfish.

Black Mussel

The black mussel occurs almost everywhere along the coast starting from Izmir in the Aegean Sea northward to Istanbul and from there eastward along the Black Sea to its eastern border at Hopa (Fig. 1). Large quantities could easily be exported, but countries such as Spain, France, and the Netherlands produce such large quantities that the market is nearly glutted. The export price is low. An expansion of the fishery in Turkey will depend on whether the foreign demand for mussels increases.

About 200 fishermen gather black mussels by diving or dredging. In a day, a diver can gather from 300 to 400 kg of mussels, and a boat using a dredge gathers from 1 to 5 t of mussels, depending on the size of dredge.

People in Turkey eat the black mussel usually stuffed with rice (Fig. 10), but also fried. Annual consumption in Turkey is about 1,000 t.

Horse Mussel

This mussel is smaller than the black mussel, its ventral shell is more convex, and its meat is more pinkish. It occurs from about Istanbul to two-thirds down the eastern coast at Kusadasi (Fig. 1). It is especially abundant with fat meats in Ayvalik Bay, about one-third the distance down the eastern coast, because waste water from some olive oil factories enrich the water, producing large quantities of phytoplankton.

Horse mussels mostly attach to stones composed of $CaCO^3$, $MgCO^3$ FeO, and SiO_2. They are soft and easily broken, and in Turkey are termed "Atilgana."

About 100–150 fishermen in Ayvalik Bay gather horse mussels during the season from October to March. Fishermen gather them using dredges and by diving. The dredge boats are about 6 m long, and have 9–10 hp engines. The

Figure 10
Mussels are usually stuffed with rice when eaten in Turkey.

dredges are 1 m wide, 0.5 m high, and the ring bag is 3–4 m deep. Two men work in each boat and pull the dredges for 5–8 minutes. The catch includes kidonya, sea urchins, starfish, and oysters, besides horse mussels. Diving is a less prominent method because it is more difficult.

The demand for horse mussels in Greece is high, and there is no trouble exporting the entire catch. From 200–600 t/year are landed from Ayvalik Bay.

The horse mussel is often smoked and preserved. After cooking, the meats fall away from the shells and are washed. The meats are then soaked in vinegar for 5 minutes, removed, dipped in olive oil, and placed on a grill where they are smoked for half an hour at 80°C. They are then stored in jars to which olive oil is added. They keep well.

Kidonya

The meat of this species is very palatable, but the species is too scarce for commercial production. Sometimes its meat is sold as the short-necked clam as the two are similar.

Arca sp.

This species also has high quality meat, but it is too scarce for much commercial production. It is sometimes exported with the horse mussel and short-necked clam from Ayvalik (Fig. 1).

The Future of Molluscan Shellfisheries

The future of the molluscan fisheries in Turkey will depend partly on the strength of foreign demand, because local demand is negligible. The black mussel is abundant, but the foreign demand has remained low.

The demand for other species produced in Turkey, however, is strong. The striped venus could also become a more important species, because finfishing is declining in the Sea of Marmara as fish are becoming scarcer. The fishermen there may switch to gathering the striped venus as a means of employment. The shortnecked clam brings the best price, but there are pollution problems in the fishing areas in Izmir Bay. The landings of oysters are limited by lack of supply.

Hatchery rearing of seafood is going to be important in the future. There were no fish farms in Turkey in 1970, but since then fish farming has grown and now there are at least 300 trout and marine fish farmers. Some farmers are becoming interested in rearing the black mussel, oyster, and short-necked clam.

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Mollusk Fisheries in Bulgaria

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ABSTRACT

The two principal mollusk species harvested along the coast of Bulgaria in the Black Sea are the black mussel, *Mytilus galloprovincialis*, and the snail, *Rapana thomassiana*. Small quantities of oysters, *Ostrea sublamellosa* and *O. taurica* also are harvested. From 100 to 120 boats harvest the mussels from wild beds. In addition, some mussel farming occurs. The harvesting of snails began in 1989 when export markets were found. From 250 to 300 boats harvest the snails in deep water, while divers harvest them at depths of 4–5 m. In 1994, at least 7,000 people in Bulgaria were engaged in harvesting, transporting, processing, and marketing mollusks.

Introduction

The Black Sea is situated between lat. 46°32' and 40°56'N and long. 27°27' and 41°42'E. The sea is 1,149 km long, 611 km wide, its average depth is 1,197 m, while its area is 413,480 km^2. Its coastline is fairly smooth with few gulfs; a few tiny islands are located near the shores.

The black mussel, *Mytilus galloprovincialis*, and the snail, *Rapana thomassiana*, are the main mollusks harvested along Bulgaria's Black Sea coast (Fig. 1). Two species of oysters, *Ostrea sublamellosa* and *O. taurica*, are present, but they are relatively unimportant for food or trade.

After 1989, statistical services in Bulgaria disintegrated. The source of data presented here for years after 1988 is from interviews of people at state-owned and private farms, harvesting firms, and firms that buy and process mollusks.

Habitat

The Black Sea has currents as fast as about 9 cm/sec. They are generated by winds and the influx of large quantities of freshwater along its northern coast. Currents in each half of the sea form two closed counterclockwise circles. A western current starts from the mouths of the Danube and Dnieper Rivers and passes the Bulgarian coast where its name is the Devil's Current. The water salinity at the surface is about 16–18‰ and, in deep water, about 22.5‰. The low salinity is due to influxes of freshwater from the rivers and rainfall. The water temperature on the surface ranges from 24°C to 28°C in summer, while in winter it is about 6°C in the open sea and 0°C along the coast. The water temperature at a depth of 75 m is about constant at 7.5°C. The color of the water is blue-green, while its transparency near the coast decreases and is from 10 to 15 m from the surface. The dissolved oxygen concentration in the water is 124–133% (Kaneva-Abadjieva, 1960).

Description of Mollusks

Black Mussel

The black mussel is the most common bottom species of the Black Sea and comprises 63.6% of the total biomass in its beds (Kaneva-Abadjieva and Marinov, 1960). It inhabits depths from 4 to 70 m, but the largest concentrations are at depths from 15 to 30 m. In the coastal zone, the mussels are attached by their byssal threads to rocks, and in the deeper places of the muddy bottom they are attached to shells of live and dead mussels, forming large congregations (Kaneva-Abadjieva and Marinov, 1963). Adult mussels have a length 30–80 mm. Mussels from the deepest areas have relatively thin shells. Severe storms can kill all mussels along shallow coasts, but new generations set and form congregations on the rocks within 6–8 months (Trayanov, 1983).

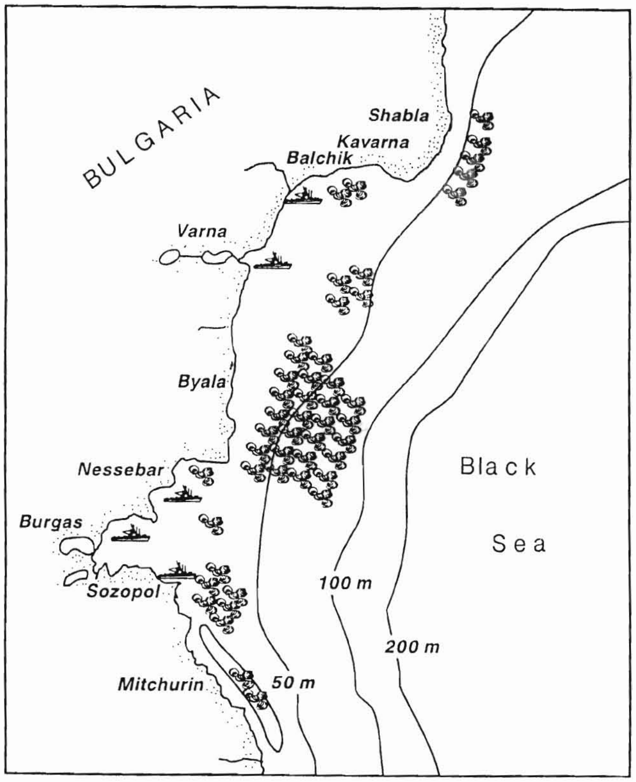

Figure 1
Distribution of mussels along the Bulgarian Black Sea coast.

The total biomass of black mussels along the Bulgarian coast is about 300,000 t, but only about 100,000 t are harvestable. The mussel beds near the Kaliakra Cape are difficult to harvest because the bottom there is rough and rocky and rough seas are common. The best locations for harvesting mussels are near Balchick and Kavarna where the mussel beds are located at depths averaging about 15 m; the yield is as much as 2.7 kg/m^2. Large concentrations of mussels occur in coastal zones near Varna, Emine Cape, Byala, Nessebar, Pomorie, and Sozopol.

Snail

The snail, *R. thomassiana*, is an exotic species, native to the Sea of Japan. It was introduced to the Black Sea by attached snail eggs on the bottoms of ships. Found first in the Black Sea in 1946, and along the Bulgarian coast in the region of Varna Bay on rocky bottom at a depth of 4–5 m in 1956, the snails afterward spread in large numbers along the entire Bulgarian coast. The reason for the snail's rapid spread in the Black Sea was a lack of natural enemies (Marinov, 1978). The snails inhabit rocky and stony zones in coastal areas as well as mussel beds on the muddy sea bottom at depths of 20–30 m.

In the past 40 years, the snails have caused substantial changes in the bottom biocenosis of the Black Sea (Konsulova, 1989). They have had a negative affect on mussels living in coastal areas as well as those on muddy bottoms at greater depths.

A campaign to exterminate the snails was begun in 1975, and special places for collecting harvested snails were set aside (Konsulov, 1978). This activity was not successful and the snails increased in numbers.

After 1989, during the transitional period to a market economy in Bulgaria, opportunities for exporting the snails to various countries increased. Snail harvests increased and exports to Turkey and later to Japan and Korea increased. The harvests have led to a decrease in the snail population.

Oysters

O. sublamellosa inhabits coastal rocks whereas *O. taurica* inhabits depths of around 20 m on hard substrate. Both oysters are sparse in Bulgaria; the largest beds are off Nessebar, Pomorie, and Sozopol. The oysters range from 40 to 55 mm in length. They have little importance as a market product, though their meat is delicious.

Mussel Harvesting

Most mussels are harvested with dredges from natural beds at depths of 15–20 m (Fig. 2). The remainder are harvested at shallower depths along rocky coasts. The fishing season lasts from March to October. Mussel dredges have metal frames and nets and are towed from boats. In coastal rocky areas at depths of 4–8 m, divers harvest the mussels.

Between 1959 and 1977, the maximum mussel harvest was 872 t in 1961. The quantity harvested from natural beds has since fallen and now ranges from 30–40 to 100–110 t/year. Variations in annual landings are not due to great changes in mussel supplies but to variations in domestic and foreign demand (Ivanov, 1979). Opportunities recently available for fishermen to harvest snails also contribute to decreased mussel catches. The population of mussels has not fallen as a result of harvesting or water pollution (Rojdestvenski, 1989; Zlatanova[1]).

Each year, from 100 to 120 boats are active, harvesting mussels during the peak harvest period. Two fishermen work in each boat. The mussels are sold at open

[1] S. Zlatanova. 1993. Mariculture in the integral management plan for development of the Bulgarian Black Sea coast. Unpubl. rep.

Figure 2
Mussel fisherman, boat, and dredge.

markets or to processing factories. Retail prices of live mussels in open markets are US$0.40/kg. The wholesale price of mussels in the factories is US$0.27/kg. From 300 to 916 kg are caught by each boat during a fishing season. If this quantity is sold by the fisherman's family at retail prices, the incomes for one fishing season range from US$120–366/boat. The incomes from mussels sold to the factories at wholesale prices range from US$81–247/boat. The fishermen's incomes from mussel catches are smaller than those from snail catches.

Mussel Culture

Bulgarian coastal aquaculture is still in its infancy. Biotechnologies for cultivating and processing mussels at sea and ashore have been developed and implemented. Two state-owned mussel farms were built in Bulgaria. The farm in Sozopol was built in 1979–80 to have an annual production capacity of 200–300 t, while the farm in Nessebar was built in 1983–84 to have an annual production capacity of 300–400 t. When they operated, both produced much less. Production of cultured mussels from the farm in Sozopol was 57 t in 1986, 150 t in 1987, and 100 t in 1988 (FAO, 1994), and the farm in Nessebar now is closed. After the changes in Eastern European countries as a result of general economic decline, mussel culture also decreased, and now production is about 60 t/year from the Sozopol mussel farm (Staykov, 1994).

In the transitional period to a market economy, many private companies have become interested in commercial mussel culture in the Black Sea. Two private mussel farms were built, and each now produces about 20–25 t/year.

Two systems of mussel cultivation are used in Bulgaria: A storm-proof floating system (Fig. 3) and a longline system. The center of the storm-proof system has a large float and an anchor, and 16 additional anchors are located around the periphery at a distance of 80 m from the center. This system consists of thick ropes, 80 m long and buoyed by suitable floats, from which thinner vertical ropes 1.5 m long are hung. Mussels are attached to the vertical ropes (Konsulov, 1980). On a structure of this type, about 30–40 t of mussels can be reared in a period of 15–16 months (Konsulova, 1974, 1988).

The longline system consists of a series of long horizontal thick ropes which are buoyed by a number of suitable floats. The system is anchored in place by concrete blocks. Thin vertical ropes to which the mussels are attached are hung from the horizontal lines (Konsulova, 1979). About 10 t of mussels are produced from 10 longlines in the 15–18 months it takes for cultivated mussels to attain market size. In contrast, mussels attain market size on wild beds in 35–40 months (Konsulova, 1978; Konsulov and Konsulova, 1989). The cultivation density depends on conditions of the region and varies from 250–1,200 mussels/m of rope (Velchev, 1983).

Snail Harvesting

Snail harvests began in 1989 when opportunities for export increased. Most snails are harvested at depths of 15–20 m using dredges similar to mussel dredges (Fig. 4). Each year, from 250 to 300 boats, each with three fishermen, dredge for the snails (Fig. 5, 6, 7). Divers harvest the remainder from rocky areas along the coast at depths of 4–5 m. Snails harvested by both methods range from 80 to 110 mm in length. The period for

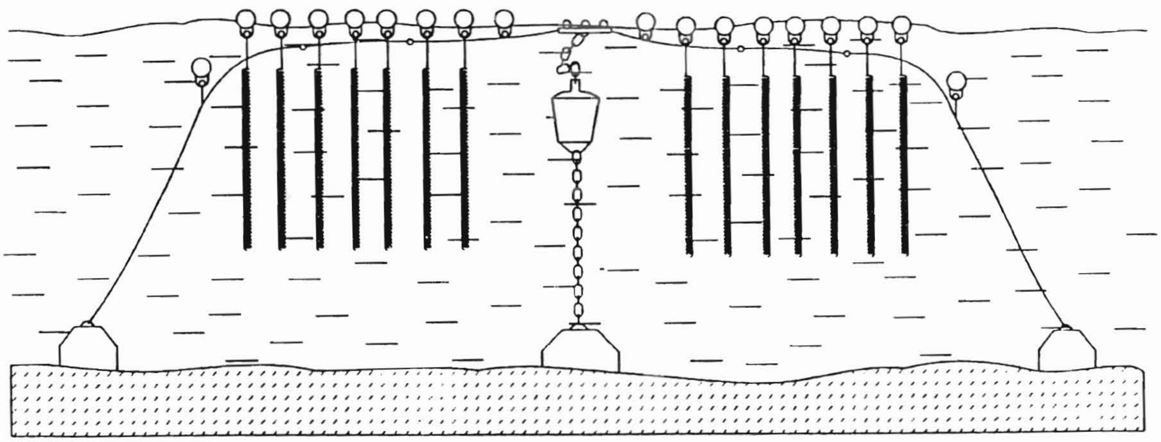

Figure 3
Storm proof system for cultivation of mussels.

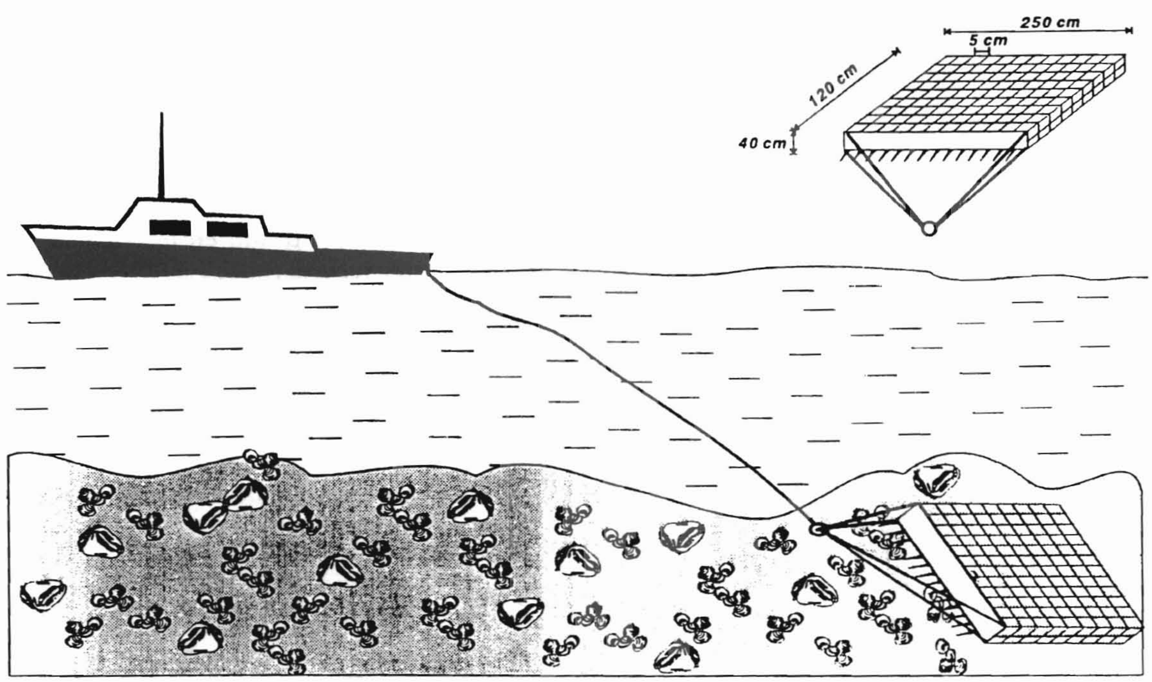

Figure 4
A dredging method for harvesting snails.

harvesting snails lasts from March to September and sometimes to November. Catches are largest in June and July. The government bans harvests during the snail reproduction period of 1–20 August.

Snail landings have increased every year. Landings were 1,500 t in 1989, 1,900 t in 1990, 2,600 t in 1991, 3,100 t in 1992, 3,900 t in 1993, and 4,500 t in 1994. About 5,000 t of snails were expected to be caught and exported in 1995. At the beginning of this fishery, the snail beds were not fully harvested. Harvests have increased as the international market demand has expanded. In the first years of snail harvesting, only Turkish firms were involved, exporting live snails. The entire snail harvest now is processed (frozen and canned) by Bulgarian firms.

In 1994, the price of live snails was US$0.41/kg. Each boat lands 15,000–18,000 kg of snails worth US$6,150–7,380 during a fishing season. A fisherman's income for a season ranges from US$2,050–2,460.

Mollusk Processing and Marketing

Mollusks in Bulgaria are either canned or frozen and are sold as culinary products. Live mollusks also are sold in markets. They are stored in polyethylene bags

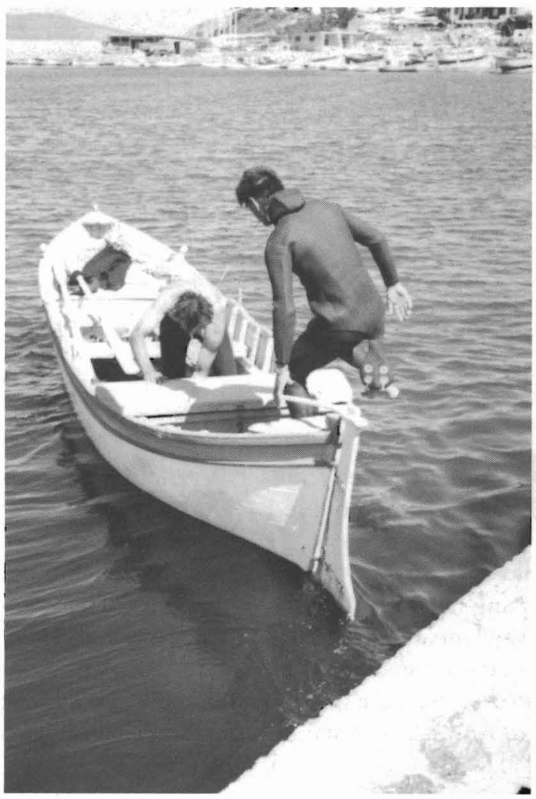

Figure 5
Boat and divers preparing to go after snails.

Figure 6
Divers with harvest of snails.

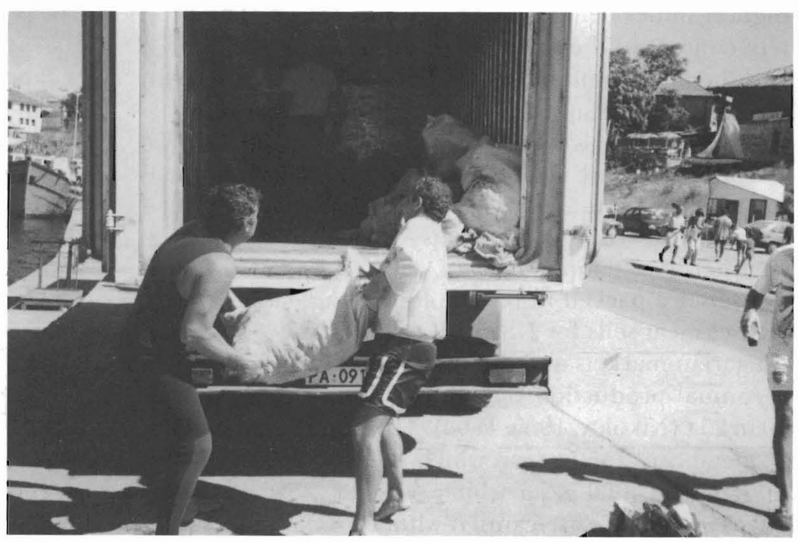

Figure 7
Fishermen loading bags of snails onto a truck.

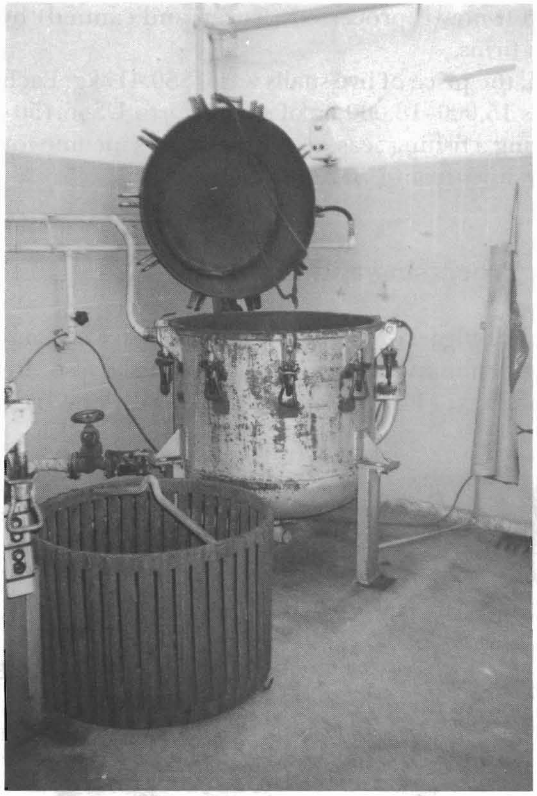

Figure 8
A retort for steaming mussels.

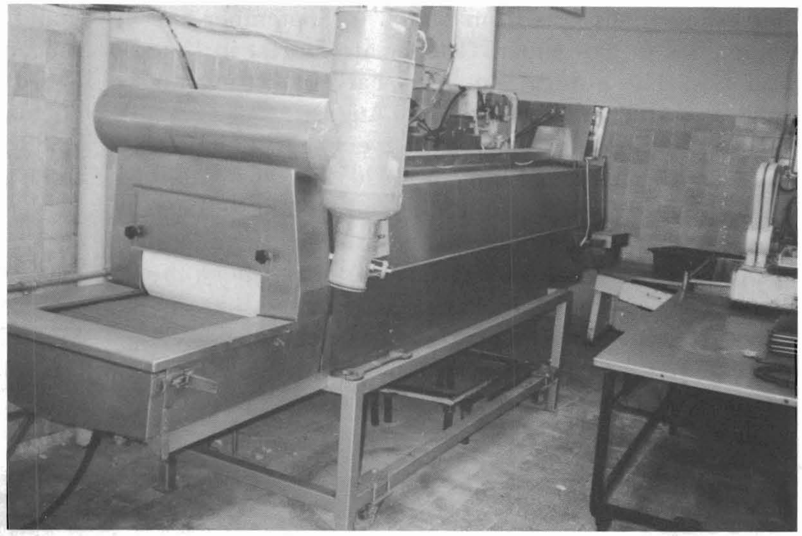

Figure 9
Machine for freezing mussel meats.

and arranged in wooden cases at 10°C (Velchev, 1984). Mollusk shells are processed into flour and used as a mineral additive in poultry feed.

Mussels have high nutritive value (Korobkina et al., 1966). The percentage of meat weight in mussels ranges from 19.9 to 28.1%, depending on the season, the highest values being in February and March. The protein content of the meat ranges from 15.99 to 17.05%, and the fat content from 1.58 to 2.31%; both vary with the season (Konsulova and Dobrovolova, 1989). Mussels are sold live, frozen, and processed.

The mussels are cleaned, steamed (Fig. 8), and then the meat is separated from the shells by special machines. The freezing of meats is done in a freezing channel at a temperature of –50°C (Fig. 9). Frozen mussels are packed in bags holding 8 kg each. Frozen mussel meat sells for US$5.1/kg. About 25% is sold in Bulgarian markets and the remainder is exported.

Annual production of canned mussels ranges from 10 to 25 t (Nikolov, 1965, 1966). The mussels are packed in metal cans (550 g/can which sells for US$3.00) and in glass jars (300 g/jar which sells for US$2.43) (Fig. 10). The mussels are canned with a special sauce, with rice, mashed potatoes, or their own shell liquor.

In shops, mussels are sold fried in flour and eggs, at a price of US$0.88/0.1 kg, and as mussel salad for US$0.73/0.1 kg. The price of mussels in restaurants ranges from US$5.50–9.50 when offered as a main course.

Snails are sold in markets as frozen or canned meat. The primary processing includes washing, steaming, and separating meat from the shells manually. The freezing of the snail meat is done the same way as with mussels. The price of frozen snail meat is US$4.50–5.20/kg. About 10–15 t of frozen snail meat is sold in Bulgaria and the rest is exported. Annual production of canned snail meat is 15–20 t (140 g/can which sells for US$0.95).

Bulgaria has 21 firms that buy mollusks. Three are state- owned and the rest are private. Mollusks are processed in 18 factories, 15 of which are private. During the fishing season of 1994, at least 7,000 people living along the Black Sea were involved in harvesting, transporting, processing, and marketing live mollusks and their products.

The Future

In the future, mollusk harvests and culture will likely increase along the Bulgarian coast because the international demand for mollusks is large. Though mussel harvests from natural beds could be increased, new private companies are interested in mussel culture.

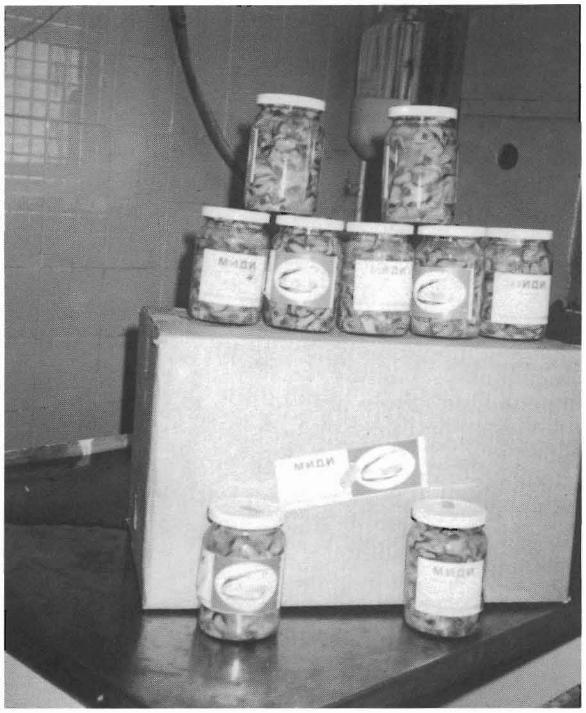

Figure 10
Jars of canned mussel meat.

Mussels remain the principal species of interest for new private farmers. Mussel culture is profitable and promising for increasing production because there are enough spat and because primary phytoplankton is high enough to promote rapid growth of mussels.

Traditional Recipes for Mollusks

Bulgarians often consume mussels as a salad. The meat from the boiled mussels is separated from the shells, and then salt, cooking oil, and lemon juice are added and, according to personal tastes, boiled potatoes and carrots may be included. Mussels are also served with rice or with carrots, onions, and mushrooms as a main course.

Oysters usually are opened, their shell liquor collected, and the meats are washed; they are then put back into their shells. Various sauces are added along with the shell liquor, and then the oysters are roasted.

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